

## Chapter 2

# Challenge–Opportunity and Mutations in China’s Economy

*WEI JI*(危机) in Chinese means challenge and opportunity are the two sides of a coin, and it also shows a challenge would become an opportunity by smart people. Although the economic growth is higher in the last decade, the marginal representative factor productivity is declining. It is a challenge in economic development in China. Is there any opportunity to increase productivity in China? On the other hand, with high energy demand, the supplies of electric power, coal, oil, and gas have been reviewed in this chapter. The great amount of energy consumption, especially the high share of coal use in the total energy consumption and chemical production, has resulted in a big amount of emissions and wasted water pollutions which have seriously damaged people’s health and living conditions. How do we meet the challenges? Should the energy demand keep fast growth to meet the economic growth in the future? Is it determined by economic gene? Are there any relations with economic mutation? These issues have been discussed in this chapter. Some challenges/opportunities have been studied on the mutation of the national economy by comparing the mutations of the national economy for the USA, Japan, and China. Our study findings show that the high energy consumption appears with a positive mutation and low energy demand coexists with a negative mutation; positive mutation and negative mutation will happen in turn alternatively in an economy. For China’s economy, it was in the high energy consumption period that showed a positive mutation which happened in 2000. And the next economic mutation will be a negative one which means that the economy will enter into a lower energy demand period. If the mutation were powerful enough to increase marginal representative factor productivity greatly and take a longer period, it would be an opportunity for China’s economy to grow healthily.

2.1 Review of Electricity and Energy Supply in China

As secondary energy, electricity is produced by primary energy, such as coal, oil, gas, nuclear, hydropower, wind, solar, biomass, and others. Electricity plays an important role in the economic production and human life because it is convenient to be used in the economic activities and household, and it will take more and more share of the primary energy. Electrification is defined as the ratio between electricity consumption and the total end energy use excluding electricity. The world’s electrification was 19.8 %, and those of the USA were 21.7 %; Japan, 25.7 %; and China, 23.1 % in 2011 [1]. “Electricity is a driving force in the changing economic landscape. A ‘great electrification’ is taking place as growth in emerging economies and changing technologies puts air conditioners, computers, and much more at the disposal of billions” [2]. It is true, and the growth of electricity demand was, is, and will be higher than other kinds of energy in China.

2.1.1 Electric Power Supply

Power sector is one of the high capital intensity sectors in the secondary industry. Power generation, transmission, and distribution need a great amount of capital for construction. As fundamental construction, the investment in power sector can also result in national economic growth. Total generation capacity in China was only 57.12 GW with serious power shortage in 1978 (Fig. 2.1), since the investment in the power sector was limited from the government budget, while other investment and foreign investment were not allowed in the planned economy in that period in China. With the economic reform, Chinese government had realized the power

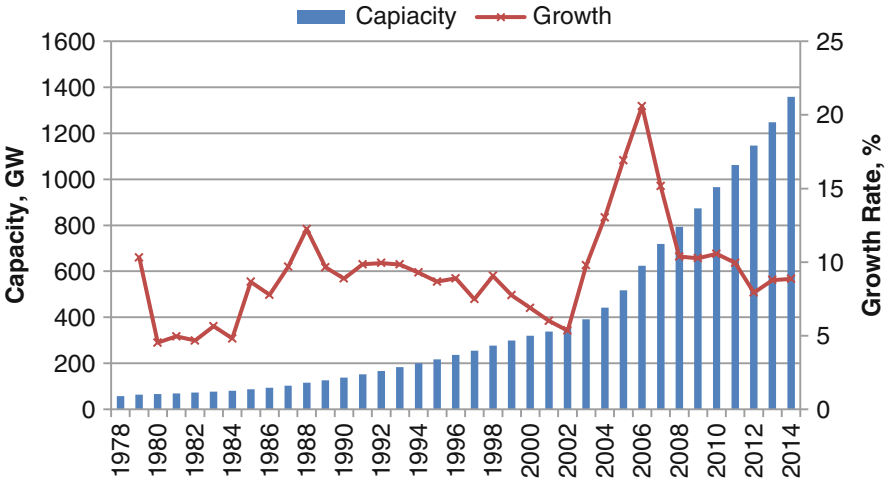
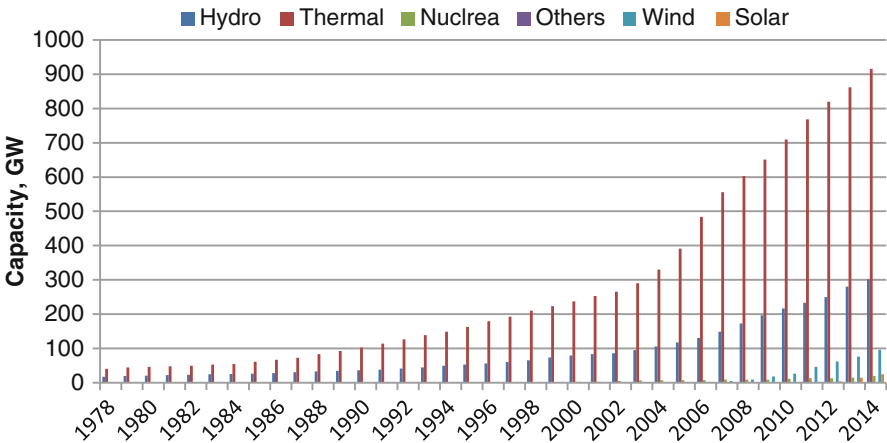


Fig. 2.1 Total power generation capacity and growth in China (Data source: statistical material of China Electricity Council over years)

shortage would limit the economic growth in the early 1980s. Thus, foreign investment in power sector had been allowed in 1984. Therefore, the generation capacity had a high growth from 8.6 % in 1985 to 12.25 % in 1988, and the total generation capacity reached 115.5 GW by the end of 1988.

In the Asian economic crisis during 1998–2000, the electricity demand was lower and there were power surplus. On the other hand, the power deregulation had been studied, and the investors found some risks in power generation. Thus, the growth of power investment was lower. However, after joining WTO since 2002, the electricity demand growth was fast and there were power shortages in China in 2003–2006. The power generation had been separated from grid in the power restructuring in 2003. The state-owned power generation companies have paid more attention on investment to meet the great electricity demand since 2003. In this case, the generation capacity has increased greatly. The new added generation capacity was 106.5 GW in 2006, and it was 110.56 GW in 2014. And then, the total power generation capacity reached 1357.95 GW, which means China became the biggest electric power country in the world in 2014. It has been shown in Fig. 2.1 that the highest growth was 12.25 % in 1998 and average annual growth was 7.93 % during 1978–2002 and the highest growth was 20.59 % in 2005 and average annual growth was 11.97 % during 2003–2014.

The coal-fired power generator has contributed a great share in China since 1978, and it will be the same case in the next 10 years because of the great availability of coal resource and lower price in China. The generation capacity of the coal-fired power plant was 39.84 GW in 1978 and reached 825.24 GW in 2014. The gas power was 55.67 GW, and coal fired and gas together as thermal power was 915.69 GW in 2014 (see Fig. 2.2). The share of coal-fired power capacity in the total generation capacity was 60.77 % in 2014, the biggest one in the world. In order to increase energy efficiency, more than 75 GW of coal-fired power plants with the unit less than 100 MW had been closed during 2006–2009. Therefore, the coal-fired



**Fig. 2.2** Power generation capacity with different technologies in China (Data source: statistical material of China Electricity Council over years)

power units that are higher than 200 MW except cogeneration units play a crucial role to produce heat and electricity. The generation units that are less than 200 MW will be closed in the next few years in China.

Hydropower takes the second share in the total power capacity. It was 17.28 GW in 1978, 105.24 in 2004, 216.05 in 2010, and 301.83 GW in 2014 (Fig. 2.2). The growth rate is 8.27 % for 36 years annually. The share of hydropower in the total generation capacity was 22.22 % in 2014.

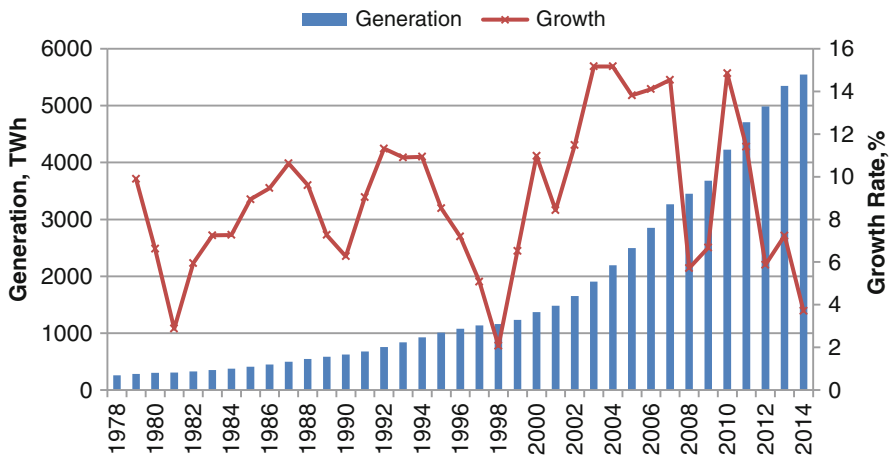
China’s nuclear power station started to generate electricity in 2000, and the capacity was only in 2.1 GW by the end of 2000. The capacity was 19.88 GW in 2014. The share of nuclear power in the total generation capacity was only 1.46 % in 2014, while it was 21 % in Japan and 10 % in the USA [3]. We can see that there is enormous space to develop nuclear power in the future in China.

As the green energy, wind power is promoted with series of incentive policies and laws in China. Wind power has grown fast since 2005. The capacity was 1.06 GW in 2005. As the biggest wind power country in the world, China’s wind power capacity was 95.81 GW in 2014. The new added capacity was 20.25 GW, 15.2 GW, 14.06 GW, and 20.33GW in 2011, 2012, 2013, and 2014, respectively.

Solar power generation is also promoted in China. The capacity of solar power was only 0.025 GW in 2009, 0.27 GW in 2010, 2.12 GW in 2011, 3.41 GW in 2012, and 14.79 GW in 2013. However, it experienced great growth by 64 % and reached 24.28 GW in 2014. With series of incentive policies, Chinese government plays an important role in promoting solar energy.

The others generation capacity illustrated in Fig. 2.2 consists of biomass and other power sources with very little share in the total power generation capacity.

People pay more and more attentions to electric power generation. As the biggest electric power country in the world, China’s total electricity generation was 5545.88 TWh in 2014 (Fig. 2.3). However, it was only 256.55 TWh in 1978,

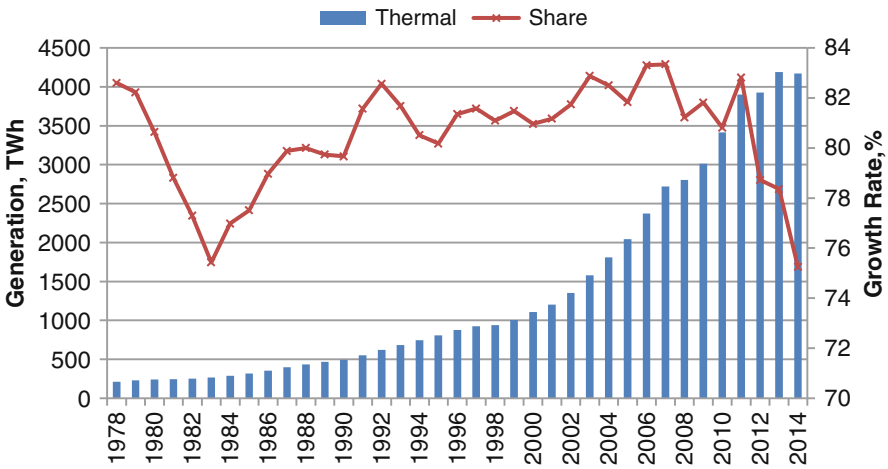


**Fig. 2.3** Total power generation and growth in China (Data source: statistical material of China Electricity Council over years)

545.06 TWh in 1988, 1006.95 TWh in 1995, 2194.35 TWh in 2004, 3264.4 TWh in 2007, and 4227.8 TWh in 2010. As for the growth of power generation, the lowest one was 2.07 % in 1998 due to the Asian crisis which damaged China’s economy seriously. The second lowest was 2.88 % in 1981 because of the transferring from the planned economy to market economy. The third one was 3.71 % in 2014 due to the decline of the impacts of investment around four trillion CNY, about 634.92 billion USD, in fundamental construction such as highway, high speed electric railway, airport, etc., during the global financial crisis in 2009. The great investment had stimulated the growths of 14.85 % and 11.41 % in electricity generation in 2010 and 2011, respectively. However, it got to its lowest in 2014. We can see in Fig. 2.3 that the annual growth of power generation was 7.76 % during 1978–1999 and 11.14 % in the 2000–2014 period. It reflects that the global economy has provided the great opportunities to China’s economic growth. After joining WTO, China’s comparative factors on lower labor cost, high working efficiency (Chinese people working hard), energy price, etc., have promoted the export. However, the labor cost has increased due to the tremendously rising house price since 2008.

Coal-fired power generation takes great share in the total power generation and more than 90 % in thermal power generation in China due to the lower coal price. As shown in Fig. 2.4, thermal power generation reached 83.34 % in 2007 and 83.3 % in 2006. Usually, the power shortage will make the coal-fired power generation generate more electricity to meet the demand. Moreover, the dry weather with few rains will also cause the same result—the hydropower station cannot generate more power without enough water. Anyway, the share of coal-fired power generation was around 75.43–70.46 % during 1978–2014. It is the highest level in the world.

The share of hydropower generation in the total power generation takes around 14.5–25 % in China. The hydropower generation is limited by water. If the weather



**Fig. 2.4** Thermal power generation and the share in China (Data source: statistical material of China Electricity Council over years)

can provide more rains, the share will be higher. As depicted in Fig. 2.5, the highest share was 24.57 % in 1983, and the lowest one was 14.18 % in 2011. The hydropower generation was 1006.14 TWh with the share of 19.23 % in 2014.

China’s nuclear power generation takes very little share around 2 % as shown in Fig. 2.6, while it was 23 % in Japan and 19 % in the USA [3]. It is clear that the share will grow fast in the next few decades due to the pressure of pollutions. The nuclear power generation was 126.21 TWh with a share of 2.28 % in total generation in 2013. The average annual growth was 15.53 % in the 2000–2014 period.

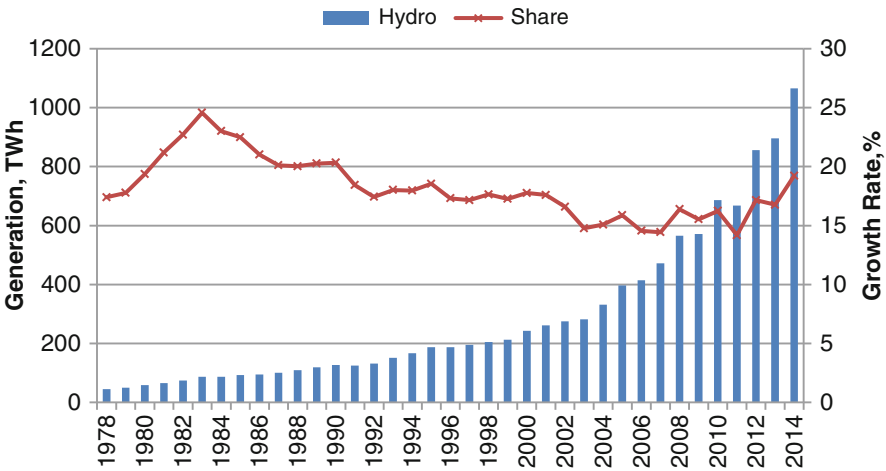


Fig. 2.5 Hydropower generation and the share in China (Data source: statistical material of China Electricity Council over years)

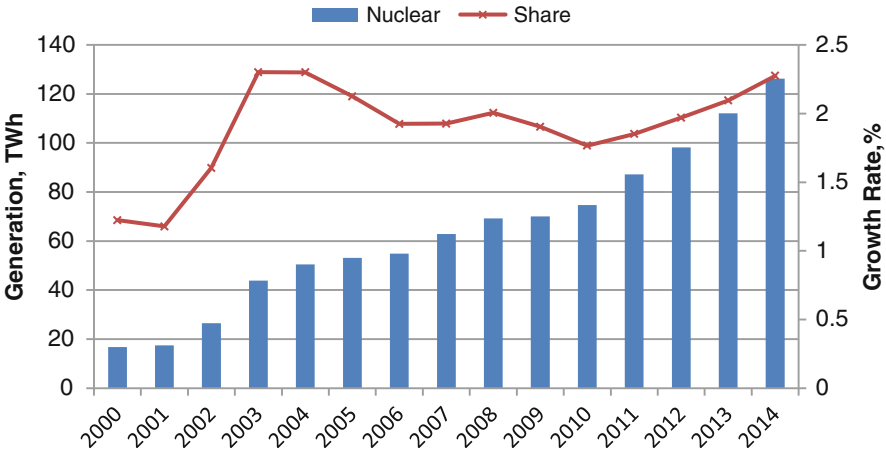


Fig. 2.6 Nuclear power generation and the share in China (Data source: statistical material of China Electricity Council over years)

China has started to develop wind power since 2005 and solar power since 2011. However, the growth of wind power generation was fast from 1.64 TWh in 2005 to 179.47 TWh in 2014. Solar power generation was 0.6 TWh in 2011, 3.6 TWh in 2012, 8.67 TWh in 2013, and 24.28 TWh in 2014 as shown in Fig. 2.7. Apart from wind and solar generation, their share in the total power generation is displayed in Fig. 2.7; it was 3.23 % in 2014. There will be substantial growth in the next decades with the promotion of incentive policies and laws in China.

In summary, nonfossil energy generation and its share in the total power generation have been shown in Fig. 2.8. It was 1371.92 TWh with the share of 24.74 % in total power generation in 2014, as the highest share since 1978 in China.

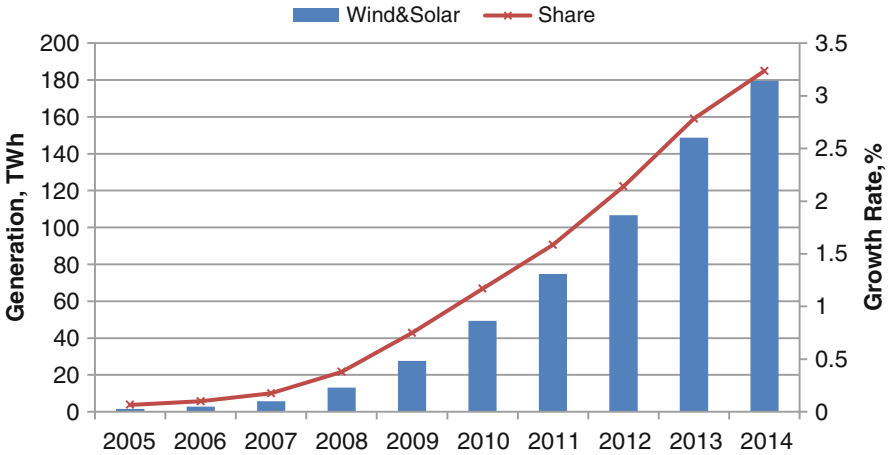


Fig. 2.7 Wind and solar power generation and the share in China (Data source: statistical material of China Electricity Council over years)

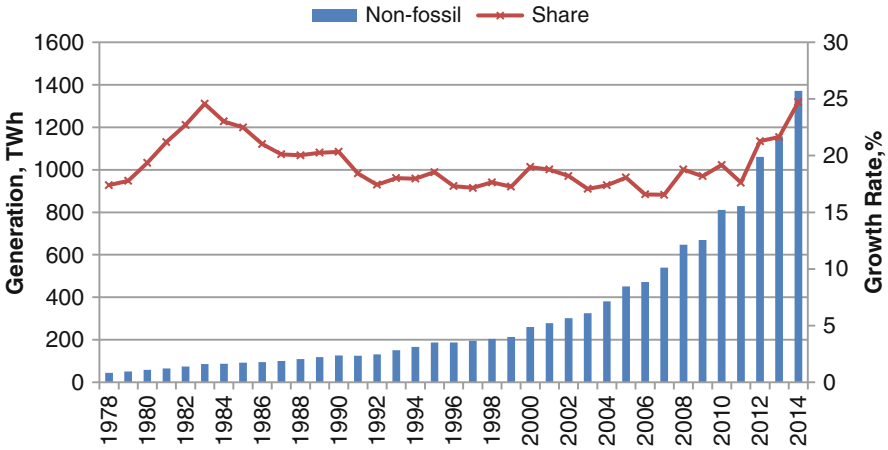
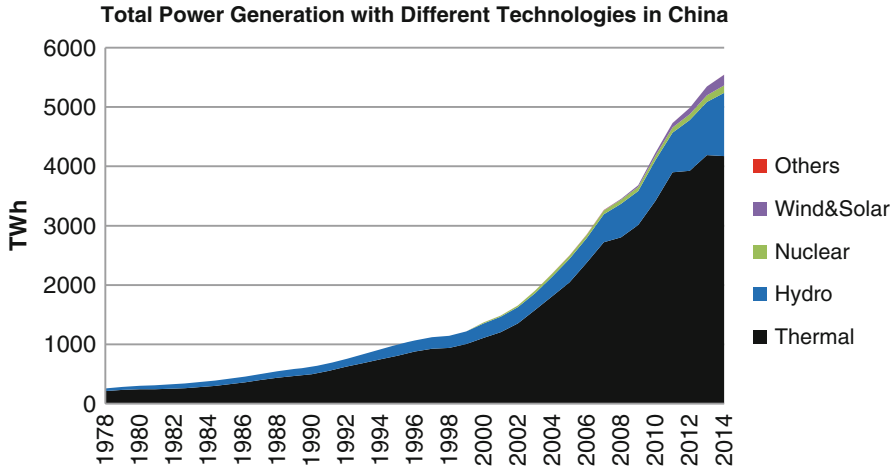


Fig. 2.8 Nonfossil energy generation and the share in total generation China (Data source: statistical material of China Electricity Council over years)



**Fig. 2.9** Total power generation with different technologies in China (Data source: statistical material of China Electricity Council over years)

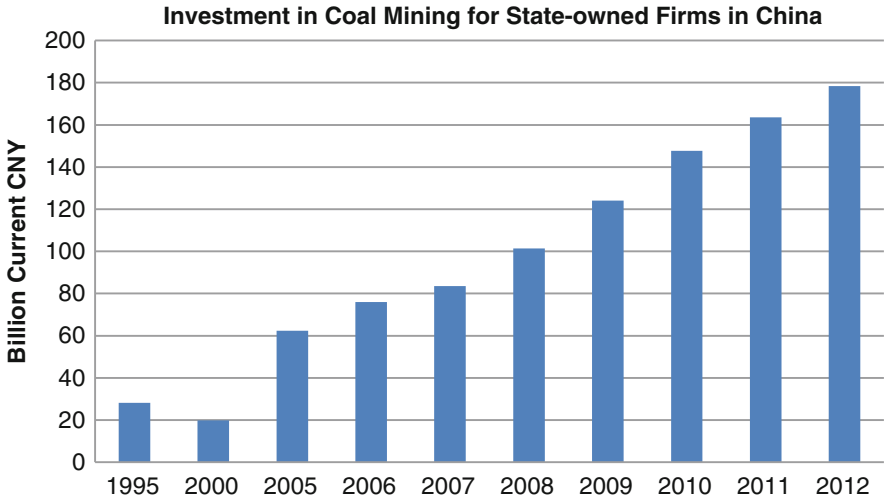
As exhibited in Fig. 2.9, the power generations with different technologies are quite different. The thermal power generation, mainly coal-fired power generation, has contributed a great share, followed by hydropower generation. However, the coal-fired power generation will be reined due to pollution, and hydropower is also limited by the availability of resources. The nuclear, wind, and solar power will grow fast in the next few decades. Therefore, the nonfossil energy generation will have a big space in the future in China.

### 2.1.2 Coal Production and Consumption

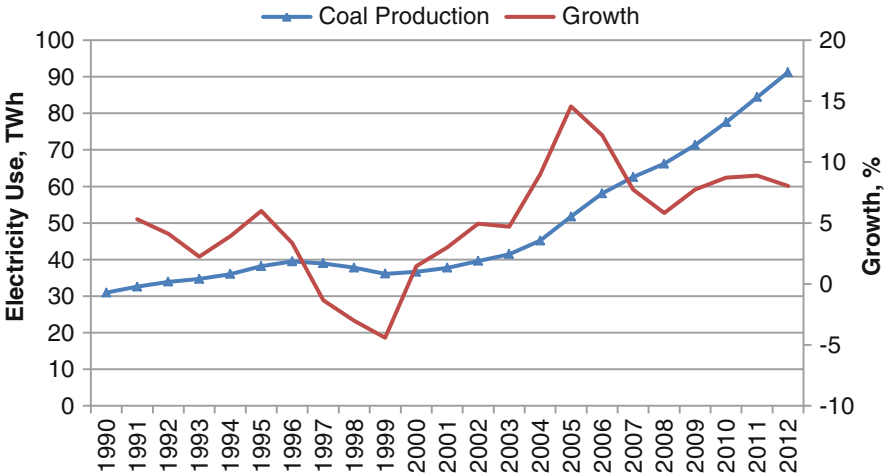
There is rich coal resource in China. During 1995–2012, the investments in coal mining and processing for state-owned firms are shown in Fig. 2.10. It was 28 billion CNY in 1995 and declined to 20 billion in 2000 because of the Asian crisis, it reached 62 billion in 2005 since the coal demand grew fast, and it was 178 billion in 2012. The coal production can be reflected by electricity consumption in coal production sector (Fig. 2.11). It was 30.92 TWh in 1990 and 91.21 TWh in 2012; the average annual growth was 5.04 % for 22 years. The lowest growth was –4.41 % during the Asian crisis in 1998, and the highest growth was 14.58 % in 2005.

The share of coal in the total energy production is around 69.4–77.8 % as displayed in Fig. 2.12. Coal production was 441.3 Mtce (million tons of coal equivalent) in 1978, 771.71 Mtce in 1990, 988.6 Mtce in 2000, and 2583.6 Mtce in 2012. However, comparing with Figs. 2.11 and 2.12, the average coal production by using one GWh electricity was quite different from 23.5 tce/GWh in 1992 to



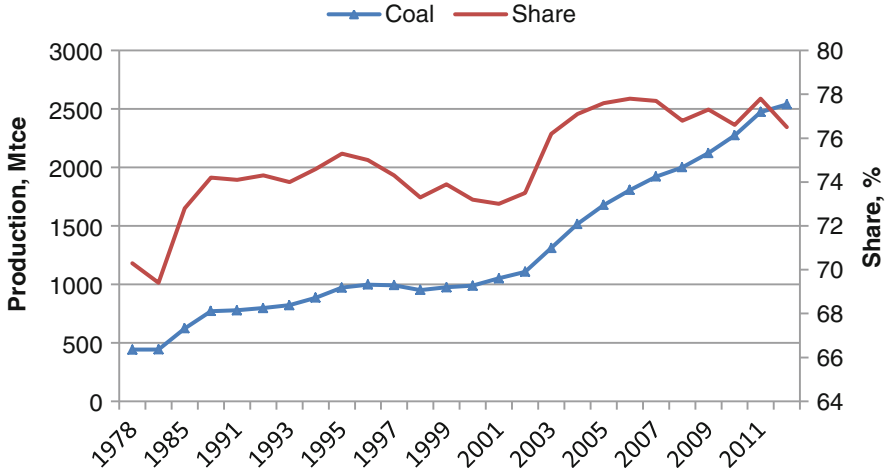


**Fig. 2.10** Investment in coal mining and processing for state-owned firms (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

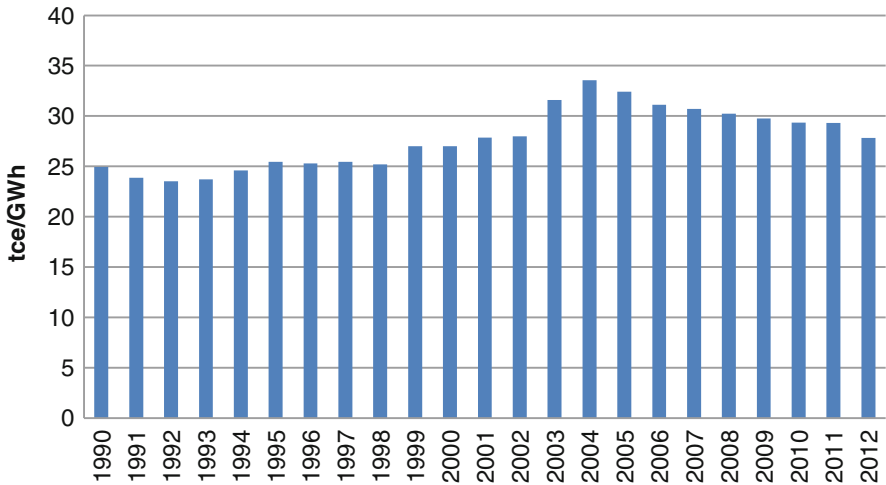


**Fig. 2.11** Electricity use and the growth in coal production in China (Data source: China Statistics Press, Beijing, China)

33.57 tce/GWh in 2004 (Fig. 2.13). It would increase with technology improvement. Maybe there are some errors in the coal production published in statistic way, since the data of electricity use in the coal production sector is quite accurate. Based on the electricity economics, the revised coal production in the 1990–2012 period is



**Fig. 2.12** Coal production and the share in total energy production in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013)



**Fig. 2.13** Coal productions by using one GWh electricity in coal sector in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

shown in Fig. 2.14. We can see that the revised coal production would be 2740.81 Mtce in 2012, which is 202.17 Mtce more than the published one.

Coal consumption is illustrated in Fig. 2.15. The share of coal consumption in the total energy consumption is around 66.6–76.2 %. The coal consumption was 404 Mtce with the share of 70.7 % in 1978, 435.19 Mtce with the share of 72.2 % in

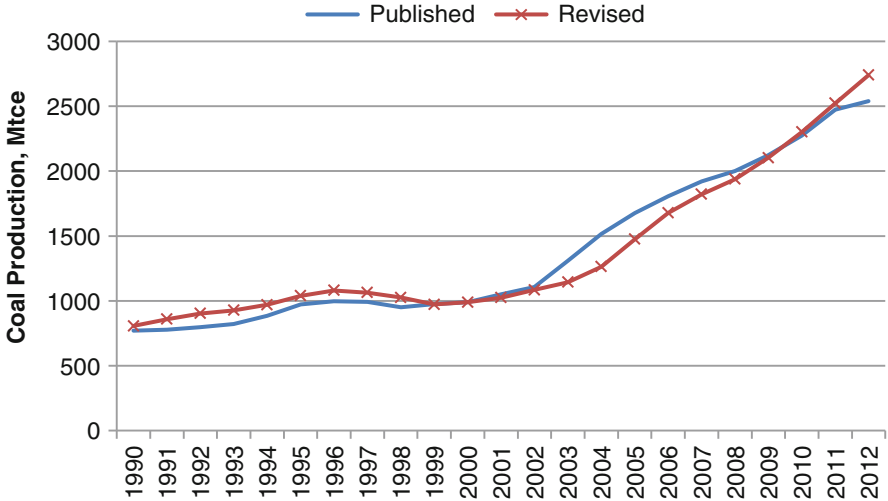


Fig. 2.14 Revised and published coal production in China

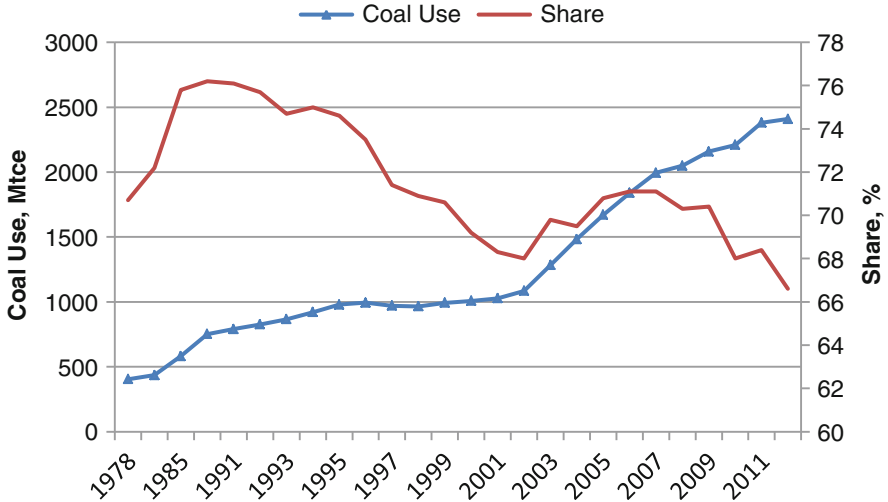


Fig. 2.15 Coal consumption and the share in total energy consumption in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

1980, 581.25 Mtce with the share of 75.8 % in 1985, 752.12 Mtce with the share of 76.2 % in 1990, 978.57 Mtce with the share of 75 % in 1995, 1027.27 Mtce with the share of 68.3 % in 2001, and 2409.16 Mtce with the share of 66.6 % in 2012.

However, since the coal production has been revised, the coal consumption ought to be revised too. Based on the coal balance, the revised coal consumption during 1990–2012 is shown in Fig. 2.16. It is revised as 2611.31 Mtce in 2012.

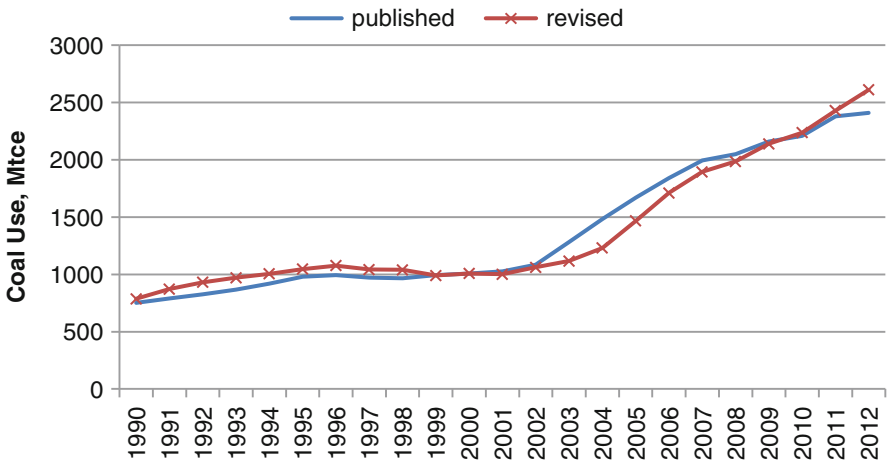


Fig. 2.16 Revised and published coal use in China

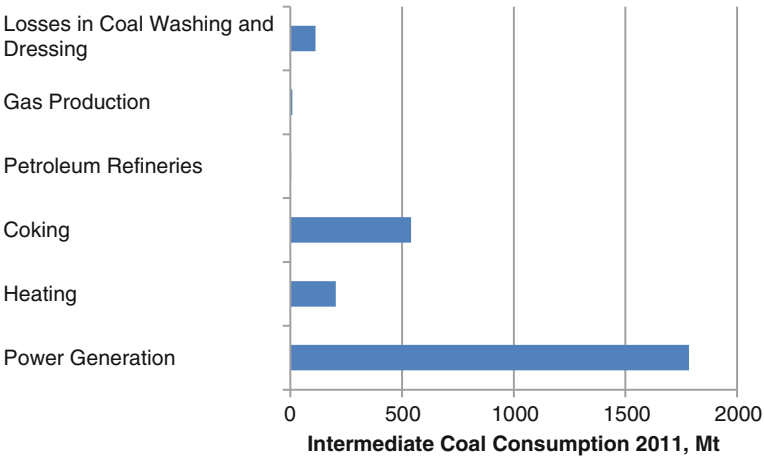


Fig. 2.17 Coal consumption in sectors in China 2011 (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

We can see that the intermediate coal consumption was around 2566 Mt in 2011, while power generation used coal 1785 Mt, cooking 540.68 Mt, and heating 202.5 Mt as shown in Fig. 2.17. Table 2.1 exhibits the coal balance from 1980 to 2012 (note: the unit shown in Fig. 2.17 and Table 2.1 is in the unit of Mt which is different from Mtce). The coal import is increasing and export is decreasing due to the lower coal price and high quality in the international markets.

**Table 2.1** Coal balance sheet (Mt)

Item	1980	1985	1990	1995	2000	2005	2010	2012
<i>Total coal available for consumption</i>	626.01	827.76	1022.21	1334.61	1367.94	2269.41	3297.72	3800.33
Output	620.15	872.28	1079.88	1360.73	1384.18	2349.51	3235	3645
Imports	1.99	2.307	2.003	1.635	2.1788	26.1711	163.095	288.411
Exports (—)	6.32	7.77	17.29	28.617	55.0647	71.7244	19.1037	9.2748
Stock changes in the year	10.19	—39.05	—42.385	0.868	36.6468	—34.554	—81.272	—123.80
<i>Total coal consumption</i>	610.09	816.03	1055.23	1376.76	1410.92	2318.51	3122.36	3526.47

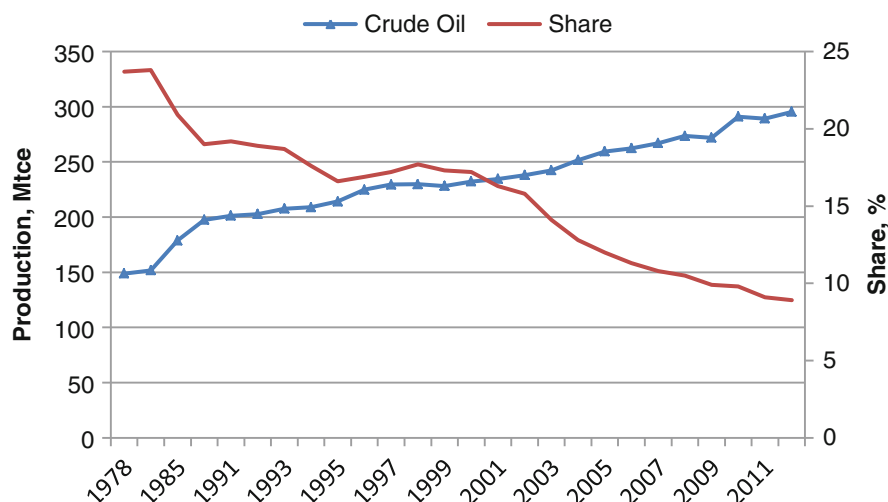
*Source:* Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China

### 2.1.3 Oil Production and Consumption

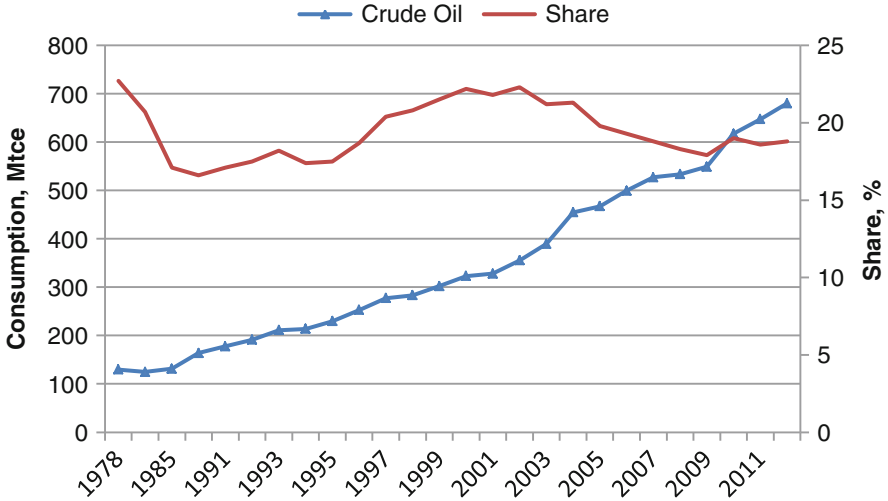
There is a lack of oil resource in China, and the oil production in recent years is further limited comparing to the high demand after joining WTO in the early of the twenty-first century. Crude oil production had increased about double during 1978–2012. As shown in Fig. 2.18, it was 148.77 Mtce with the share of 23.7 % in 1978, 151.69 Mtce with the share of 23.8 % in 1980, 197.45 Mtce with the share of 19 % in 1990, 232.28 Mtce with the share of 17.2 % in 2000, and 295.34 Mtce with the share of 8.9 % in 2012. The share in the total energy production declined continually during 1978–2012 since the oil resource was not enough to meet the demand.

Oil consumption has grown fast in the past three and a half decades. It was 129.72 Mtce in 1978 and 680.06 Mtce in 2012 (Fig. 2.19). The average annual growth was 4.99 % for 34 years. The share of oil consumption in the total energy consumption waved around 20 % during 1978–2012 as shown in Fig. 2.19. The distribution of oil consumption in some sectors is shown in Fig. 2.20, in which the secondary industry use was 180.5 Mt, transport and storage used 160 Mt, and non-production consumption was 40 Mt in 2011.

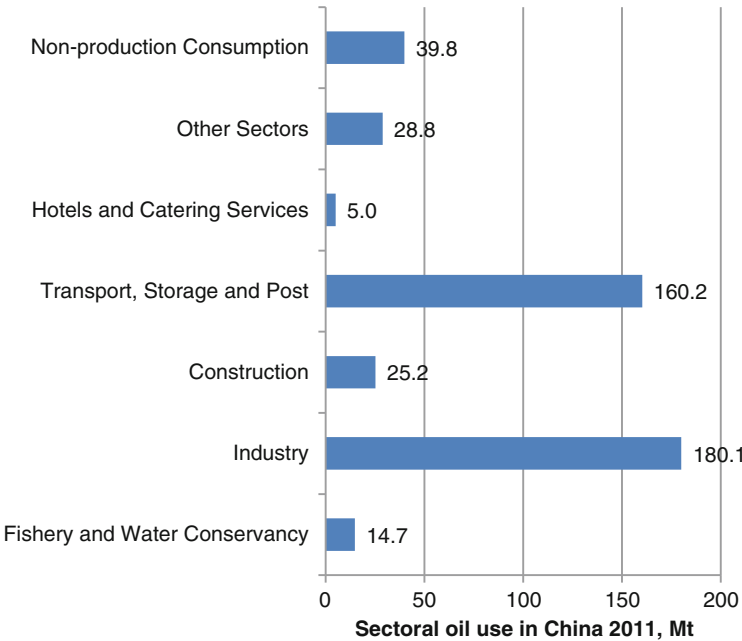
As for the balance of oil production and international trade in 2011 (see Fig. 2.21), the total production of oil was 202.9 Mt, the import oil was 315.9 Mt, the net import was 274.76 Mt, and the share of import in the total oil consumption was 60.55 %, while it was 61.9 % in the USA in 2009. With the growth of living standard level, the oil consumption in transport will increase fast, and then, the share of import oil will grow fast too in the near future.



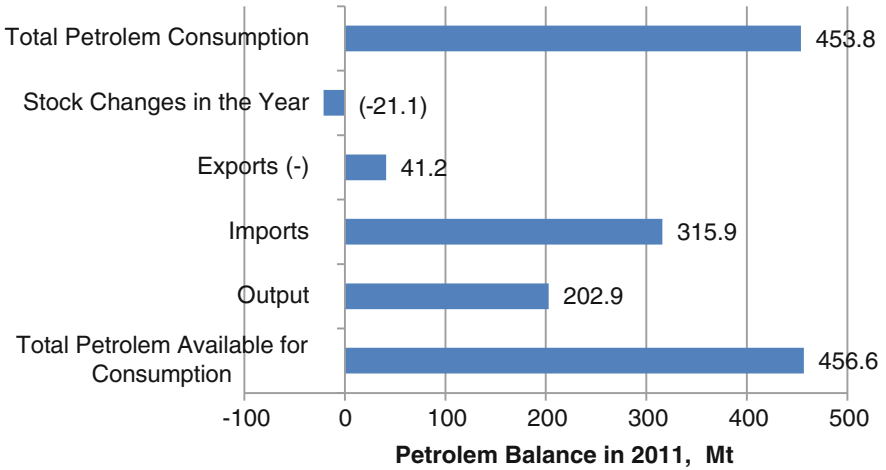
**Fig. 2.18** Crude oil production and the share in total energy production in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



**Fig. 2.19** Oil consumption and the share in total energy consumption in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



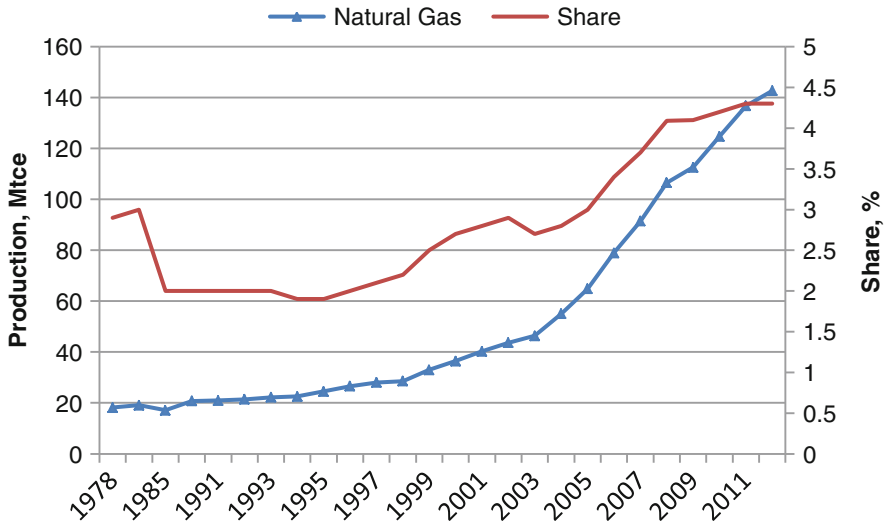
**Fig. 2.20** Oil consumption in sectors in China 2011 (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



**Fig. 2.21** Oil balance in China in 2011 (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

**2.1.4 Natural Gas Production and Consumption**

Natural gas resource is not enough to meet the high demand and the gas production is limited in China. Figure 2.22 illustrates the natural gas production and the share in the total energy production in 1978–2012. The production increased slowly from



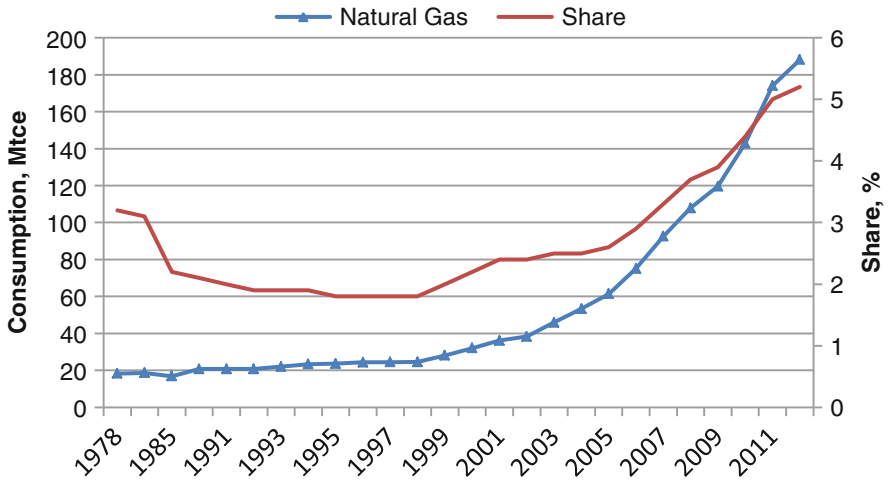
**Fig. 2.22** Natural gas production and the share in total energy consumption in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



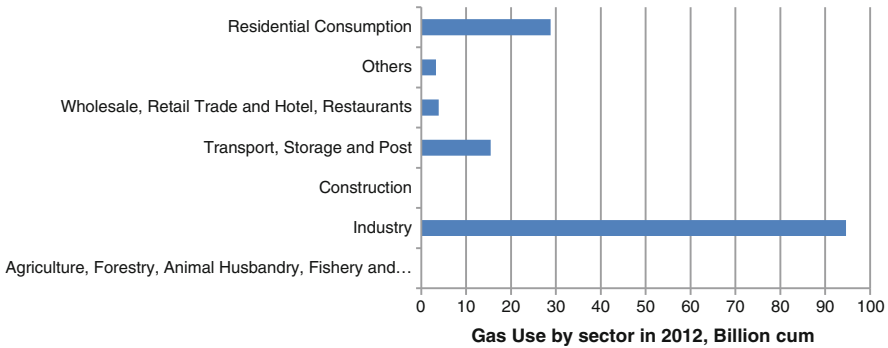
18.2 Mtce in 1978 to 43.69 Mtce in 2002, while it was 142.7 Mtce in 2012. The share increased from 2 % in 1985 to 4.35 % in 2012.

Comparing Figs. 2.22 and 2.23, we can see that the curve of gas consumption is similar to the curve of gas production. It means there were very few gas imports before 2010. The share of gas in the total energy use appeared like a “U” form as shown in Fig. 2.23, from 3.1 % in 1980 down to 1.8 % in the 1990s and up to 5.2 % in 2012

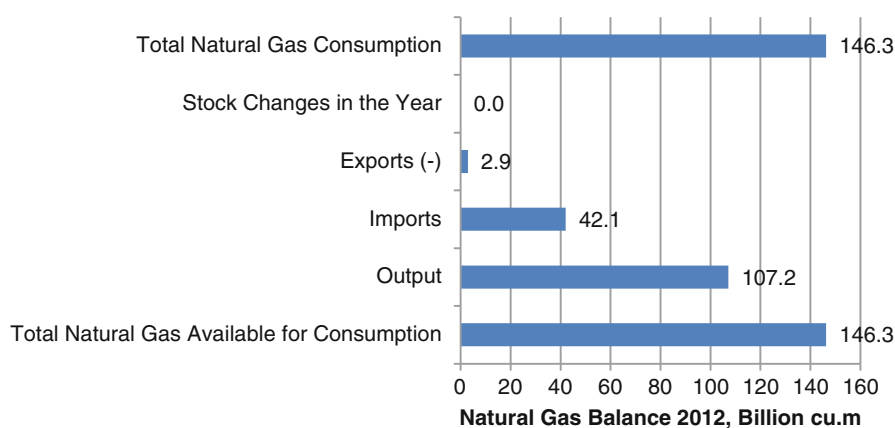
Total gas consumption was 146.3 billion cubic meters in 2012 in China, while secondary industry used 94.7 billion cu.m, residential consumption consumed 28.8 billion cu.m, and transport and storage and post used 15.5 billion cu.m as depicted in Fig. 2.24.



**Fig. 2.23** Gas consumption and the share in total energy consumption in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



**Fig. 2.24** Natural gas consumption by sector in 2012 in China (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



**Fig. 2.25** Natural gas balance in China in 2012 (Data source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

As for natural gas balance in 2012 (see Fig. 2.25), the total gas production was 107.2 billion cu.m, the import was 42.1 billion cu.m, and the net import was 39.8 billion cu.m, which takes 26.77 % in the total gas consumption. It is expected that the share will increase fast in the future since the demand grows quickly and gas resource is limited in China.

### ***2.1.5 Hydro-, Nuclear, and Wind Power Production and Consumption***

Electricity production from hydropower, nuclear power, and wind power is shown in Fig. 2.26 (note: it is measured in Mtce). It was 19.46 Mtce in 1978 and 341.8 Mtce in 2012 and increased 17.57 times in 34 years. The share in the total energy production increased from 3.1 to 10.3 % in the period.

The electric power consumption from hydropower, nuclear power, and wind power is shown in Fig. 2.27. It is the production minus line loss. It was 340 Mtce with the share of 9.4 % in the total energy consumption in 2012.

### ***2.1.6 Total Energy Production and Consumption***

As displayed in Fig. 2.28, the total energy production was 627.7 Mtce in 1978, 1039.22 Mtce in 1990, 1350.48 Mtce in 2000, and 3318.48 Mtce in 2012. The growth rate was -2.72 % in the Asian crisis in 1998 and 5.37 % in global financial crisis in 2008.

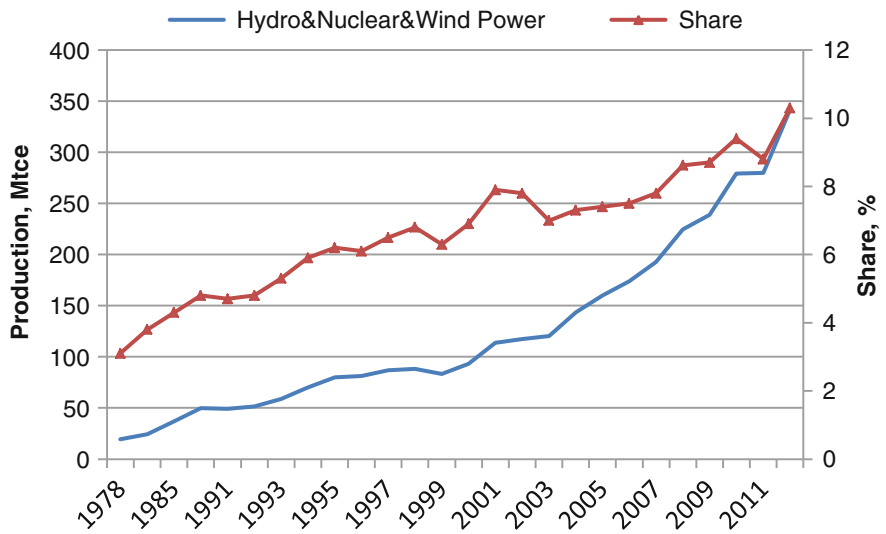


Fig. 2.26 Hydro-, nuclear, and wind power generation in China

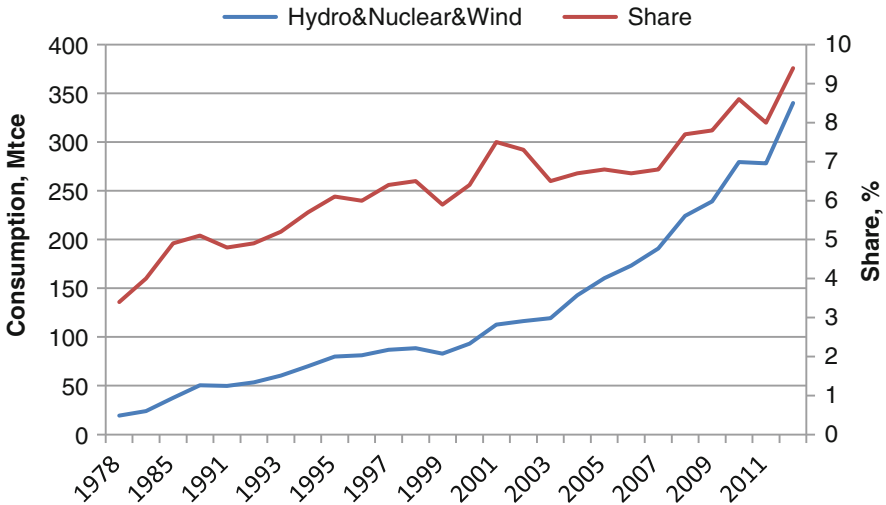
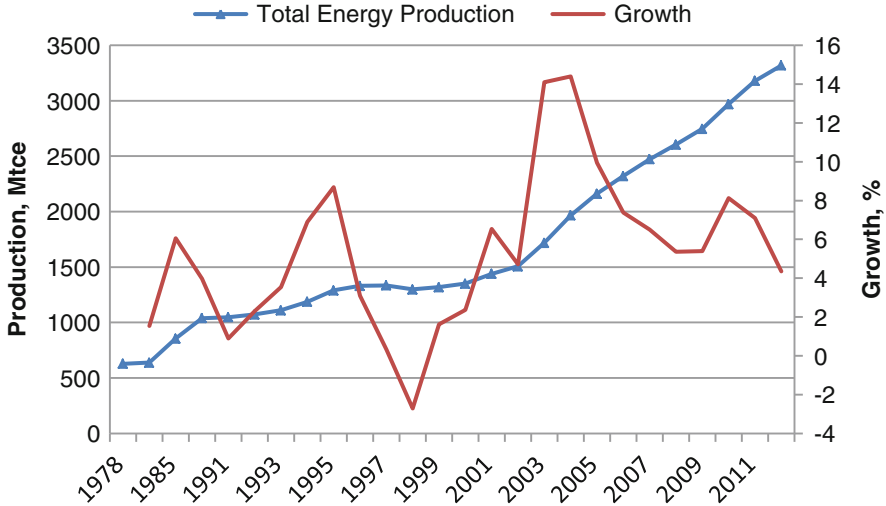


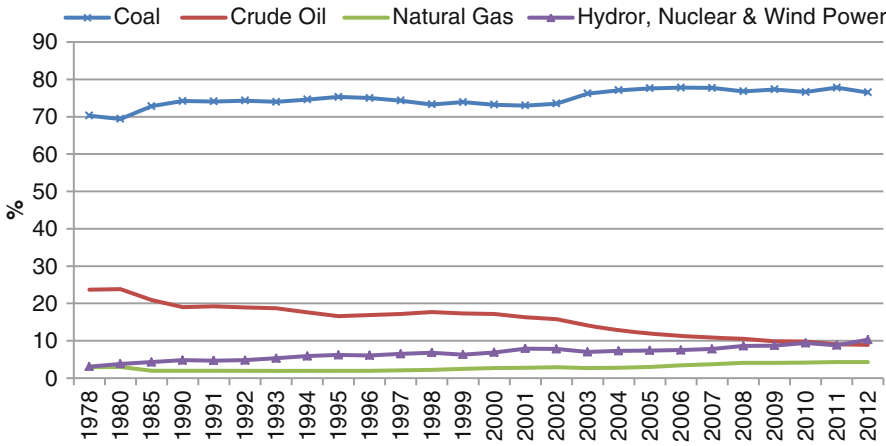
Fig. 2.27 Hydro-, nuclear, and wind power consumption and the share in total energy consumption in China

The composition of the energy production is illustrated in Fig. 2.29. The highest share was coal around 76.5 %; the second one was hydro-, nuclear, and wind power in 10.3 %; the third one was oil in 8.9 %; and the last one was gas in 4.3 % in 2012.

The total energy consumption is shown in Fig. 2.30. It was 571.44 Mtce in 1978, 1455.31 Mtce in 2000, and 3617.32 Mtce in 2012. The composition of the energy consumption is shown in Fig. 2.31. The highest share was coal around 66.6 %; the



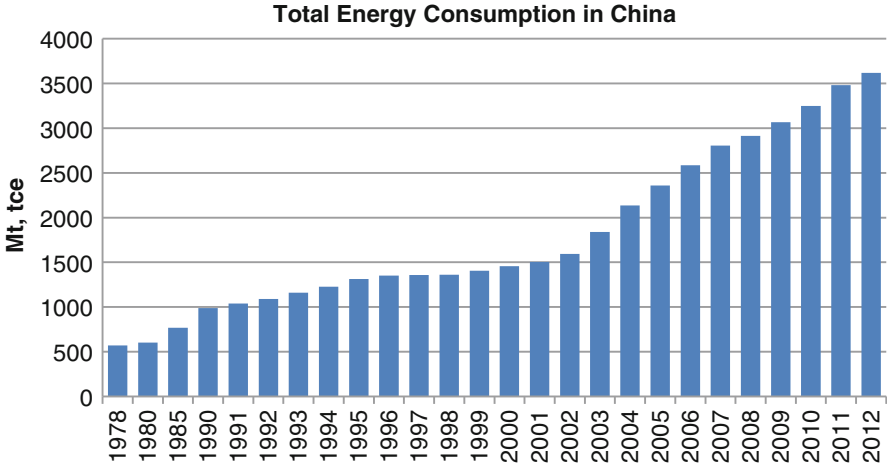
**Fig. 2.28** Total energy production and growth in China (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



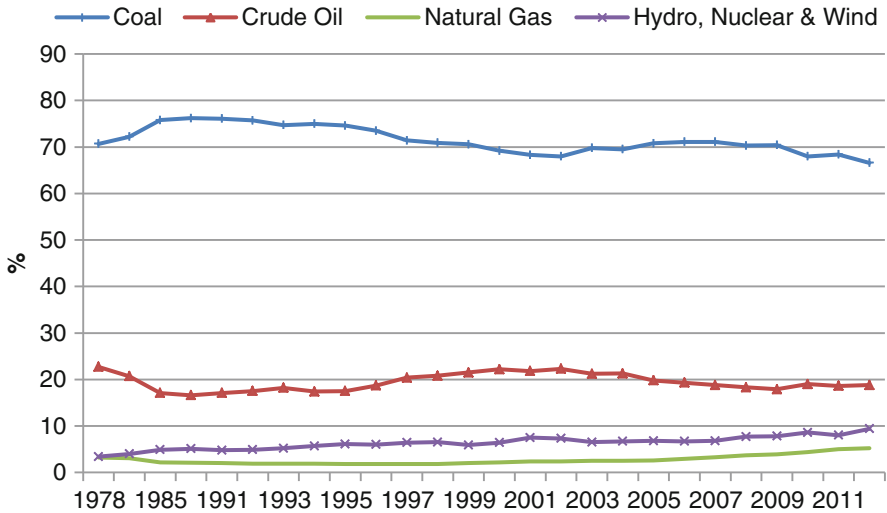
**Fig. 2.29** Composition of energy production in China (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

second one was oil in 18.8 %; the third one was hydro-, nuclear, and wind power in 9.4 %; and the last one was gas in 5.2 % in 2012.

Energy consumption in manufacture in 2011 is exhibited in Fig. 2.32; iron and steel take the highest one at 588.97 Mtce, manufacture of nonmetallic mineral products takes the second highest one at 300 Mtce, and the third one is electric power, gas, and water supply at 260 Mtce.



**Fig. 2.30** Total energy consumption in China (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

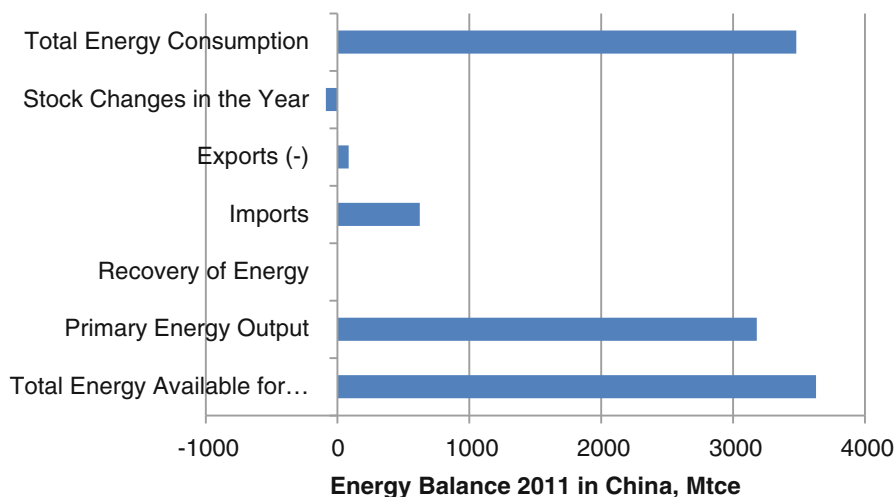


**Fig. 2.31** Composition of energy consumption in China (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

The energy balance in 2011 is shown in Fig. 2.33. We can see that the total energy consumption was 3480 Mtce, primary energy production was 3179.86 Mtce, energy import was 622.6 Mtce, and export was 84.47 Mtce. The net energy import in the total primary energy production was 17 % in 2011, and it will enlarge fast in the future.



**Fig. 2.32** Energy use in manufacture in China 2011 (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)



**Fig. 2.33** Energy balance in China 2011 (Source: Department of Industry and Transport Statistics & National Energy Administration of China, China Energy Statistical Year Book 2013, China Statistics Press, Beijing, China)

Among the energy resources in China, coal resources account for more than 96 %, petroleum resources account for 2.4 %, and natural gas resources account for 1.2 %, indicating that petroleum and natural gas resources are very limited. Per capita possession of natural energy resources of China is less than half of the world average level, wherein per capita possession of petroleum resources only accounts for 17 % of the per capita value of the world and natural gas resources only account for 13.2 % of the per capita value of the world. The conditions of insufficiency of energy resources characterized by major shortage in coal resources and poor gas and oil will not change greatly in the next 20 years.

## 2.2 Emissions

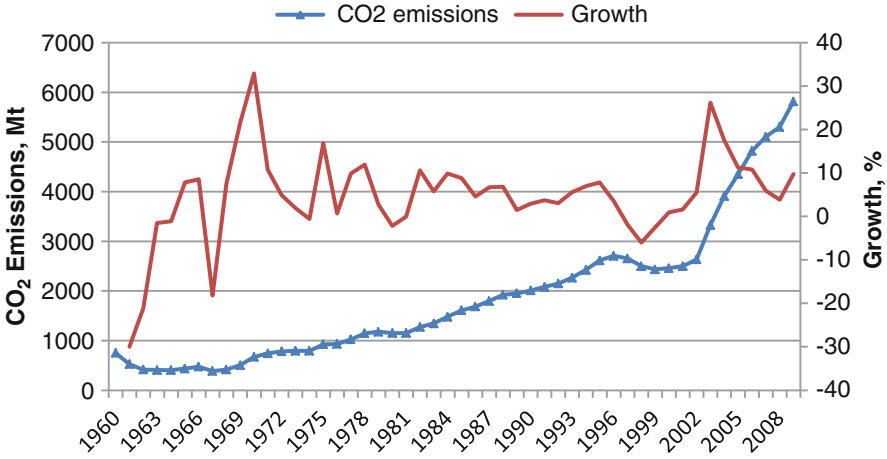
Large proportion of coal will lead to more serious environmental issue and health problems. From the energy consumption mixture, it can be seen that the coal resources accounted for approximately 66.6 %, petroleum for approximately 18.8 %, natural gases for 5.2 %, and nonfossil energy for 9.4 % in 2012. Due to excessively large proportion of fossil energy, pollutant discharge will significantly worsen living environment of the people.

Large import volumes of petroleum impose high risks on the security of energy resources. The potential of petroleum production is only limited in around 200 million tons due to the resource, and China has to import great amount of petroleum to meet the demand; therefore, its dependence on import share was very high and reached America's record of 61.9 % in 2009 [4]. Such high dependence on the foreign supply will increase the risks to procurement and transportation of petroleum and the like.

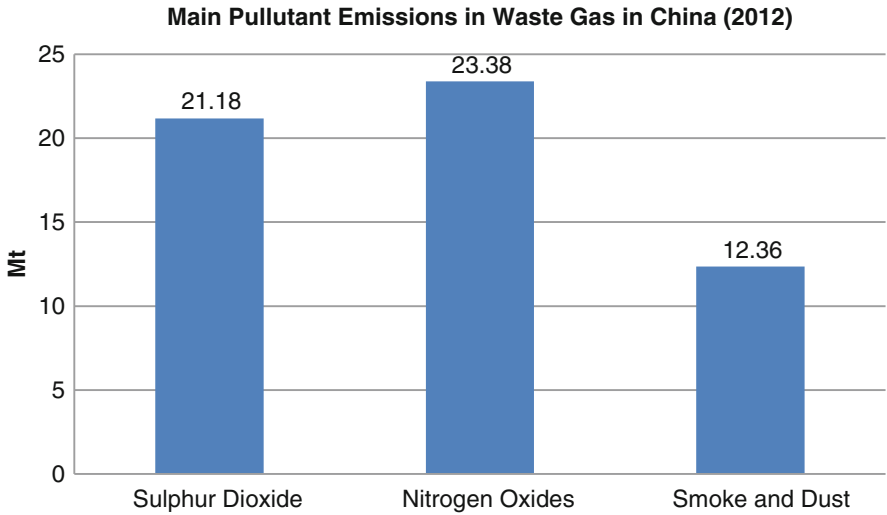
With the fast growth of energy consumption, especially the coal that contributes a high share of energy use, air pollution from coal combustion was, is, and will be the main source of emissions. On the other hand, as a result of the rapid growth of China's economy, especially in the period of industrialization, lots of manufacturing firms have productions in their business. Therefore, big amount of industrial wastewater was, is, and will be a serious problem for people's health in China.

### 2.2.1 Air Pollutions

Since coal is the major energy resource in China, there would be serious problem on emissions such as carbon dioxide (CO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and other pollutants. The emissions seriously affected China's air quality and people's health. It will be poorer and poorer in the next few years. It is shown in Fig. 2.34 that the CO<sub>2</sub> emissions were less than 1000 Mt before 1976; it was 1950 Mt in 1989, less than 2000 Mt; it was 2635 Mt in 2002; however, it reached 5818 Mt in 2009.



**Fig. 2.34** CO<sub>2</sub> emissions in China (Source: The World Bank, <http://data.Worldbank.org/country/china>)



**Fig. 2.35** Main pollutant emissions in waste gas in China (Source: China Statistic Press, China Statistical Year Book 2013)

The emissions of sulfur dioxide SO<sub>2</sub> is also very serious in China. According to China Statistic Yearbook, SO<sub>2</sub> emission was 13.25 Mt in 1985, 14.94 Mt in 1990, and 18.91 Mt in 1995. The average growth rate of SO<sub>2</sub> emission was 3.62 % annually during 1985–1995, and it was 1.14 % during 1995–2005. The main reason for the lower growth rate of SO<sub>2</sub> emission during 1995–2005 is that the filter equipment has been promoted in coal-fired power plant. Figure 2.35 shows that SO<sub>2</sub> emission was 21.18 Mt, nitrogen oxide emission was 23.38 Mt, and smoke and



dust emission was 12.36 Mt in 2012. The emissions have resulted in chemical rains in large scale time and time again, especially in the middle and east region of China. The acid rain area was very little, and the range of annual average  $pH$  value of precipitation was in 5–5.6 in 1980; the area grew to about one-third of the country and the  $pH$  was in 5–5.6 in 1990; the area was about half of the country with  $pH$  of 4.5–5 in 2000; it was poor in 2005 wherein the area had reached to 75 % of the country, having a  $pH$  less than 4.5.

### 2.2.2 Water Pollutions

*China has seven major river systems, and nearly one-half of them are polluted. The quality of 86 % of the urban river sections is below official standards [5].* Total wastewater discharge was around 36 billion tons in 1985 and was 37.2 billion tons including 22.19 billion tons for industrial discharge in 1995. However, after that, it increased quickly. The industrial wastewater discharge was 24.3 billion tons and residential wastewater discharge was 28.14, and the total was 52.44 billion tons in 2005 and 68.47 billion tons in 2012 [6]. The wastewater discharge in main cities is shown in Fig. 2.36; we can see that Shanghai has contributed the biggest at 2192.44 Mt; the second is Guangzhou, capital of Guangdong province, at 1528.33 Mt; and the third one is Beijing, capital of China, at 1402.74 Mt.

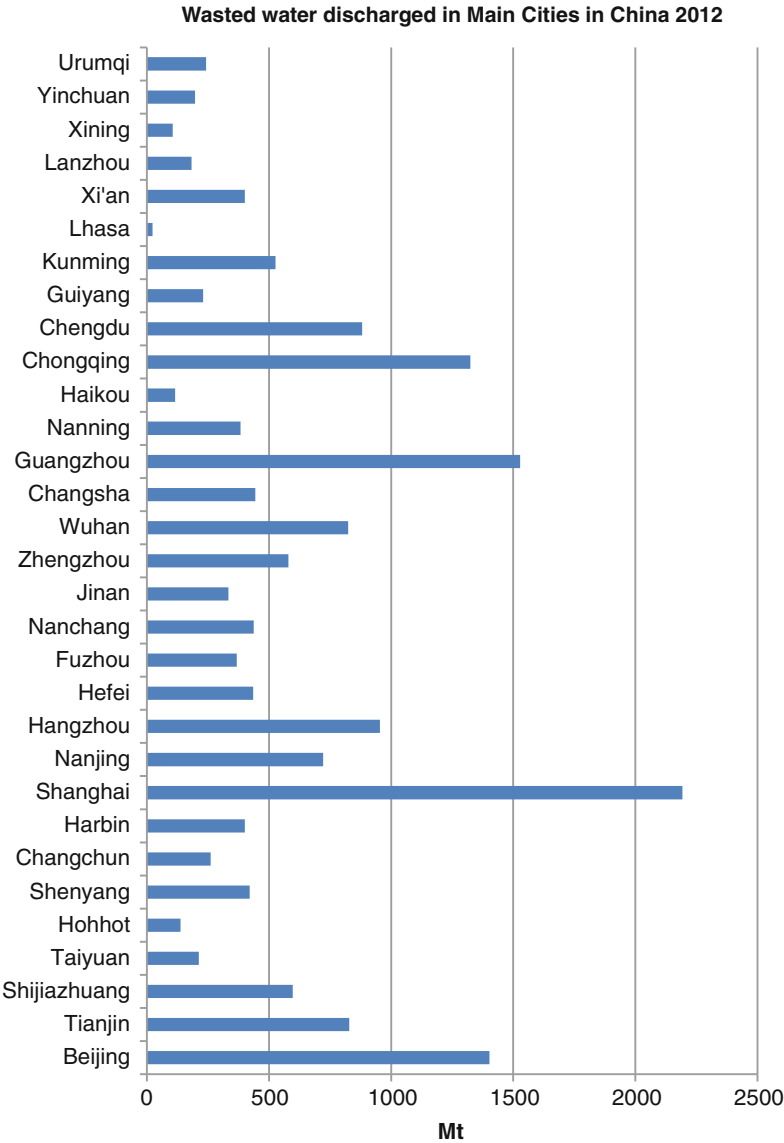
Chemical oxygen demand (COD) is an index to measure the water by reducing the pollution; the higher the value, the more polluted the water. Figure 2.37 shows the COD discharged in main cities in China. Clearly, the highest one is Chongqing, the city near Yangzi river, with the COD of 402.8 kt; the second one is Harbin, capital of Helongjiang province in the northeast of China, with the COD of 314.69 kt; and the third one is Shenyang, capital of Liaoning province, with the COD of 260.49 kt in 2012.

Mercury discharge in the wastewater is also serious as shown in Fig. 2.38. According to the amount of mercury discharge, the number one city was Urumqi, capital of Xinjiang municipality region, at 14.43 Mt; the second city was Fuzhou, capital of Fujian province, at 12.99 Mt; and the third one was Naning, capital of Guangxi Gui municipality region, at 5.22 Mt in 2012.

The organic water pollution emissions from 2003 to 2007 in China are shown in Fig. 2.39. It was 7.066 kt per day in 2003, 7.96 kt per day in 2004, and 9.43 kt per day in 2007.

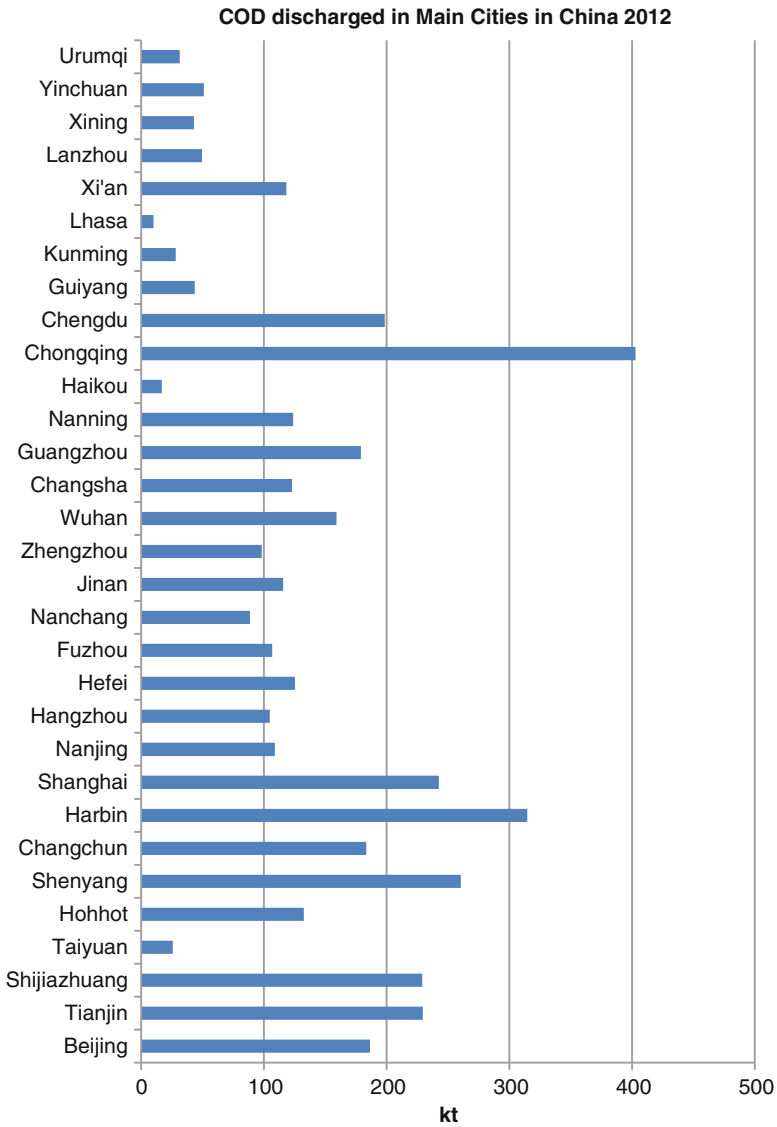
### 2.2.3 People's Health Problems

The air pollution, water pollution, and other pollutions have resulted in serious problems on people's health in China. It makes people to pay more attention to health issues, such as taking exercise, Chinese medicine, medical insurance, and



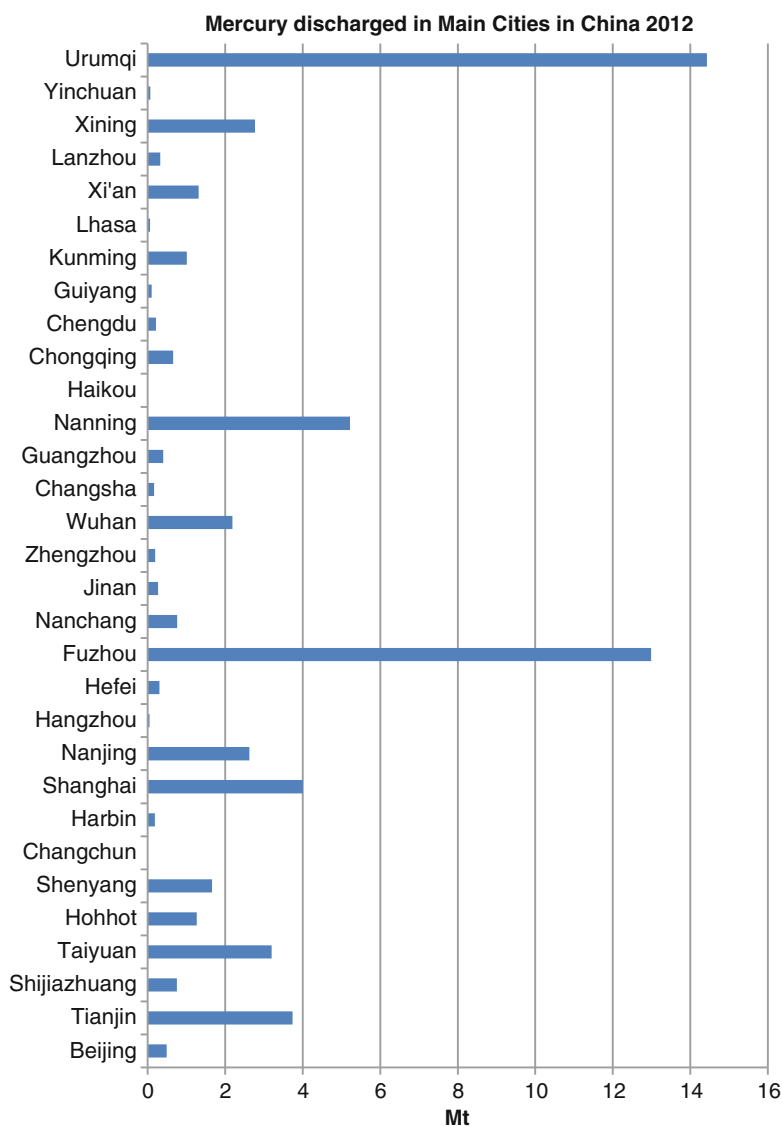
**Fig. 2.36** Wastewater in main cities in China (2012) (Source: China Statistic Press, China Statistical Year Book 2013)

health expenditure. It is clear that the payment on health is growing fast, especially in the last 10 years. Although GDP growth is in high speed, the share of health expenditure in GDP grows quickly too. It is shown in Fig. 2.40 that the share of public health expenditure in GDP was almost unchanged around 1.7–1.8 %, while



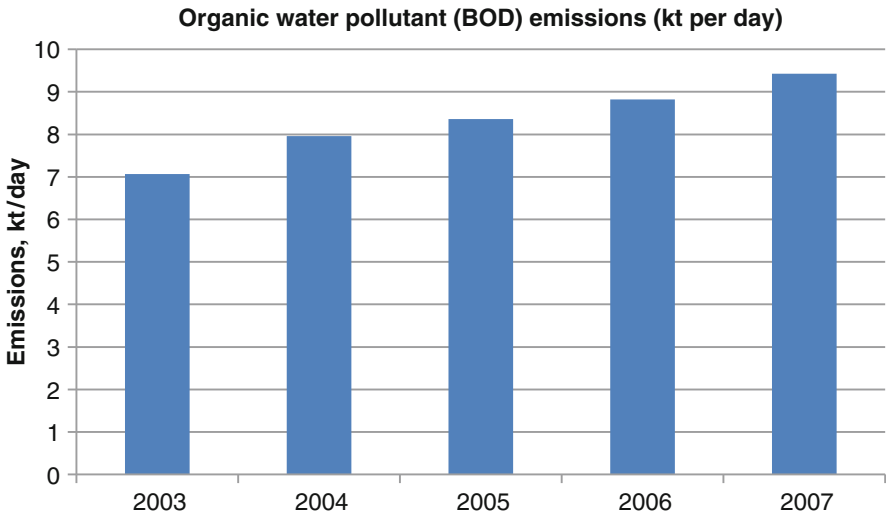
**Fig. 2.37** COD in wastewater in main cities in China (2012) (Source: China Statistic Press, China Statistical Year Book 2013)

total health expenditure share in GDP had grown from 3.7 % in 1995 to 4.78 % in 2005. It reveals that the personal health expenditure is growing due to the reform from government pay the cost to personal pay it. The reform has led to distrustful and mistrustful state between patient and doctor; thus, the government tries to pay more on health cost. Therefore, the share of public health expenditure in GDP

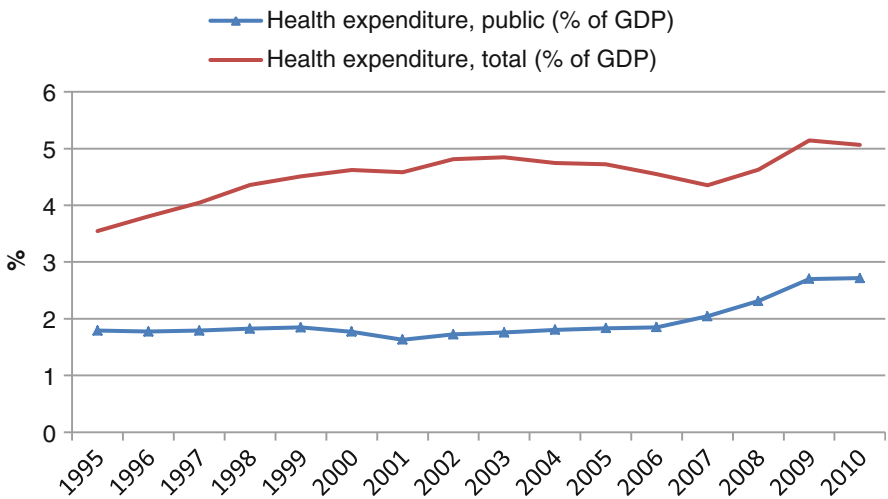


**Fig. 2.38** Mercury in wastewater in main cities in China (2012) (Source: China Statistic Press, China Statistical Year Book 2013)

increased from 2006 as shown in Fig. 2.40. The total health expenditure has also grown considerably since 2006 because the people’s health has become poorer and poorer. The health expenditure per capita varied from 62.3\$ (constant 2005 international dollar and exchange rate by purchasing power parity) in 1995 to 214.88\$ in 2006 and then to 378.9\$ in 2010 (see Fig. 2.41). The average annual growth rate of the health expenditure per capita was 13.71 % during 1995–2006, and it was



**Fig. 2.39** Organic water pollutant emissions each day in China (Source: The World Bank, <http://data.Worldbank.org/country/china>)



**Fig. 2.40** Health expenditure in GDP in China (Source: World Bank, <http://data.Worldbank.org/country/china>)

16.37 % during 2007–2010. However, the average annual GDP growth was 9.96 % during 1995–2006, and it was 8.43 % during 2007–2010. The situation requires people to rethink: What is the goal of economic growth? Does it have more value to pursue economic growth itself or focus on the ultimate goal of the economic development?

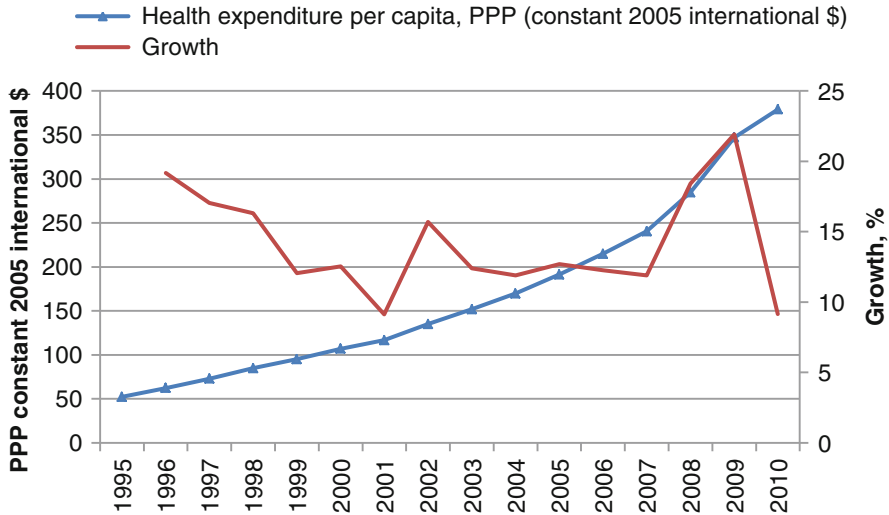


Fig. 2.41 Health expenditure per capita in China (Source: World Bank, <http://data.Worldbank.org/country/china>)

### 2.3 Economic Mutation

Pollutions are a serious problem in China because people are paying more attention to health. Is it worth having more pollution for economic growth? Is it possible to decrease the growth of energy demand to get blue sky and clean water to ensure comfortable living conditions? It has to be studied from economic system. If the gene of the economic system changes, perhaps it would be an opportunity for China's economy to solve pollution problems in the near future. As introduced in Chap. 1, *E-GDP* function has four characteristics of gene: replication, mutation, evolution, and uniqueness. A mutation of economy will happen if the intercept of the *E-GDP* function changes from negative to positive or from positive to negative, and then, the slope of the function would change greatly. Economic mutation will indicate a poor economic state, such as lower marginal representative factor productivity and stagflation of the economy; and it may also mean a good economic state, such as high marginal representative factor productivity and lower energy demand. It depends on the integration of technology improvement and innovation, interrelationships between sectors of the economy, and other factors of global economy. It would make the marginal representative factor productivity change greatly. We will compare the economic mutations in the USA, Japan, and China to find if there is a way to convert challenge to opportunity in China's economy development.

In order to discuss conveniently, average GDP (*AGDP*) of electricity can be calculated in two ways: *AGDP(S)* means the published GDP(*S*) divided by electricity use *E* and *AGDP(E)* is based on the calculated GDP(*E*) from *E-GDP* function divided by electricity use *E*. Both of them are called *AGDP* and the differences between them are very little unusually.

On the other hand, the slope of the  $E$ -GDP function signifies the  $MGDP$  in the period. A mutation implies that  $MGDP$  goes up and down alternatively. If the intercept of the  $E$ -GDP function is negative, the slope of the function will be large, i.e., the  $MGDP$  will be up. The mutation with  $MGDP$  going up is called negative mutation, and the function is called negative  $E$ -GDP function. If the intercept of the  $E$ -GDP function is positive, the slope of the function will be small relatively, i.e., the  $MGDP$  will be down, and the mutation is called positive mutation and the function is called positive  $E$ -GDP function. Thus, the negative mutation means the economy grows healthily, while the positive mutation indicates that the economy is in some problems or sick. The slope of the  $E$ -GDP function shows the  $MGDP$ , and it is also the marginal representative factor productivity of the economy.

### 2.3.1 Mutations of the Economy in the USA

For the US economy, three mutations happened in 1976, 1986, and 1991 since 1949. Thus, there were four periods of the US economy: 1949–1976, 1977–1986, 1987–1991, and 1992–2011. The  $E$ -GDP functions are shown as follows:

1949–1976:

$$GDP(E) = 3.153E + 1362.2 \quad (2.1)$$

1977–1986:

$$GDP(E) = 6.3484E - 2875.7 \quad (2.2)$$

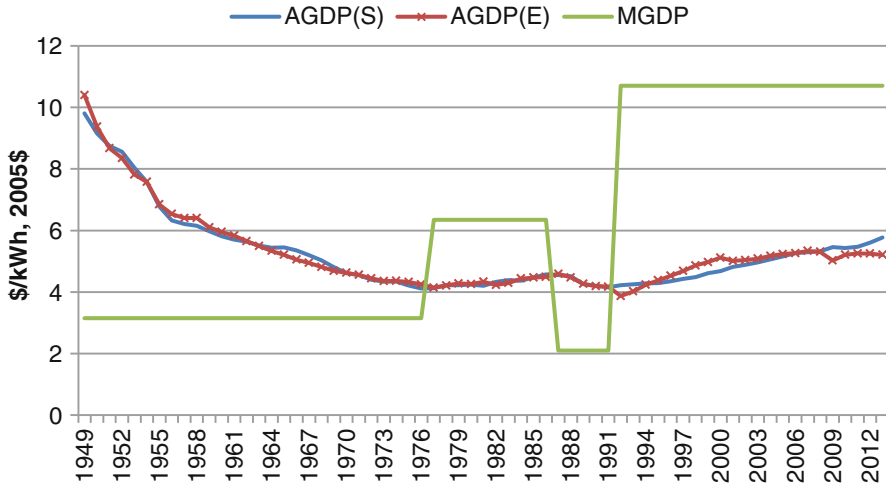
1987–1991:

$$GDP(E) = 2.098E + 4001.9 \quad (2.3)$$

1992–2013:

$$GDP(E) = 10.703E - 13407 \quad (2.4)$$

The  $E$ -GDP function in formula (2.1) was a positive function; the  $MGDP$ , marginal representative factor productivity, was relatively small (as shown in Fig. 2.42); the  $AGDP$  was larger than  $MGDP$ ; and  $AGDP$  decreased with an increasing  $E$  during 1949–1976. Since a negative mutation happened in 1977, the  $MGDP$  had increased from 3.153\$/kWh to 6.3484\$/kWh, and the intercept of the  $E$ -GDP function had changed from positive to negative as shown in formulas (2.1) and (2.2). Why can the mutation show that  $MGDP$  experiences a big growth? One reason is the growth of productivity caused by technology improvement and



**Fig. 2.42** *AGDP* and *MGDP* with mutations in the USA (Data source: Bureau of Economic Analysis, <http://www.bea.gov/> Energy Information Administration USA, Annual Energy Review 2013 <http://www.eia.gov/aer>)

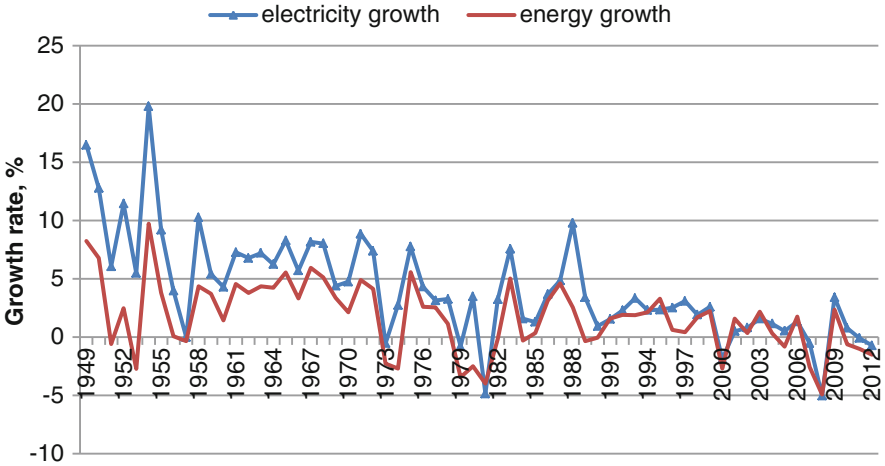
innovation. Another reason is the energy efficiency impacted by oil crisis in 1973, and also the high oil price makes the production of high energy intensity products transfer to other countries, i.e., the change of economic mix. It can be verified from the share change of the secondary industry value added in GDP. The share of secondary industry in GDP had decreased to 3.616 % during 1949–1976, while it had decreased to 4.191 % during 1977–1986. As for *AGDP*, it was decreasing from 1949 to 1976 because the intercept of formula (2.1) was positive. It is clear that the negative mutation renders the economy a growing productivity.

Another mutation happened in 1987; it was a positive mutation in which *MGDP* decreased to 2.9765\$/kWh deeply during 1987–1991 (Fig. 2.42). What were the reasons for that? It is very difficult to know the details. Since *AGDP* was bigger than *MGDP*, it was decreasing with an increasing *E* during 1987–1991. It is a poor mutation for the economy. Fortunately, it takes only a short period, and another mutation, a negative mutation, happened in 1992.

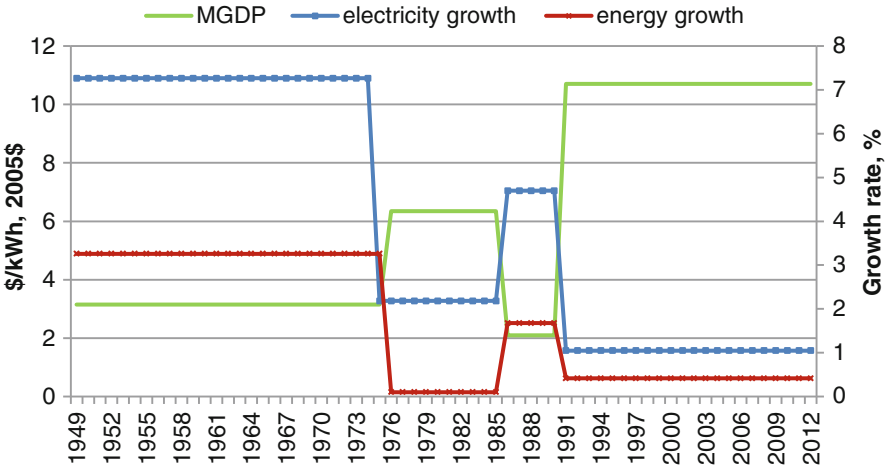
The *E*-GDP function is negative as shown in formula (2.4). The *MGDP* has increased to 10.703\$/kWh since 1992; the main reason is probably the Internet technology applications. The *AGDP* is less than *MGDP*, and *AGDP* keeps increasing since 1992. Figure 2.42 shows that there is a big space for the growth of *AGDP*. The negative mutation is beneficial to the economy.

The primary energy consumption in the USA was 31.98 quadrillion Btu in 1949. The electricity consumption in the three industries was 188 TWh in 1949. The annual energy and electricity growth rates are in decline trends as depicted in Fig. 2.43. However, it is very clear to reflect the feature of each period (Fig. 2.44) as follows:





**Fig. 2.43** Energy and electricity growth rate in the USA from 1950 to 2012 (Data source: Bureau of Economic Analysis, <http://www.bea.gov/> Energy Information Administration USA, Annual Energy Review 2012 <http://www.eia.gov/aer>)



**Fig. 2.44** MGDP, electricity growth rate, and energy growth rate with mutations in the USA (Data source: Bureau of Economic Analysis, <http://www.bea.gov/> Energy Information Administration USA, Annual Energy Review 2013 <http://www.eia.gov/aer>)

1949–1976: a positive mutation happened in 1949, the *MGDP* was relatively lower (3.15\$/kWh), and annual average growth rates of primary energy consumption and electricity consumption were relatively higher (3.26 and 7.27 %)..

1977–1986: a negative mutation happened in 1977, the *MGDP* was relatively higher (6.349\$/kWh), and annual average growth rates of primary energy consumption and electricity consumption were relatively lower (2.18 and 0.098 %)..

1987–1991: a positive mutation happened in 1987, the *MGDP* was lower (2.098\$/kWh), and annual average growth rates of primary energy consumption and electricity consumption were higher (1.68 and 4.7 %).

1992–2013: a negative mutation happened in 1992, the *MGDP* was higher (10.703 \$/kWh), and annual average growth rates of primary energy consumption and electricity consumption were higher (0.59 and 1.18 %).

We can see that when a negative mutation happened, the *MGDP* gets higher and the growth rates of energy and electricity consumption turn lower; and when positive mutation happened, the *MGDP* is lower and energy and electricity growth rates will be higher. It shows that mutation could indirectly affect the energy and electricity demand. It is also reflected in Figs. 2.43 and 2.44 that the energy growth rate is always lower than electricity growth, which means the growing up of electrification level is the direction of energy consumption. Shown in Fig. 2.44, we can find that energy efficiency had played an important role during 1977–1991 because the electricity growth was relatively lower; and electrification has played a significant role since 1992 because the electricity growth is relatively higher compared with primary energy consumption growth.

In summary of the mutations in the US economy, the positive mutation during 1949–1976 locked longer in lower marginal representative factor productivity; the negative mutation in 1977 showed a large increase in marginal representative factor productivity; it was a good opportunity to increase the productivity with lower energy consumption. The positive mutation in 1987 brought about a big decrease of *MGDP* with higher energy growth; it indicated a sick economy which is a challenge. However, the period took only 5 years. Fortunately, another negative mutation happened in 1992, and the *MGDP* had increased largely, which meant the opportunity of enhancing productivity with lower energy growth in the USA.

### 2.3.2 Mutations of the Economy in Japan

In order to show the mutation feature of an economy, we take a case study in Japan, for example. As mentioned in Sect. 1.1.2 in Chap. 1, the *E-GDP* function of Japan’s economy during 1965–2010 is shown in formula (1.8). However, it can be divided into four periods, namely, 1965–1973, 1974–1988, 1989–2000, and 2001–2010, and three mutations happened in 1974, 1989, and 2001. The mutations mean big changes of marginal GDP of electricity. Thus, the four *E-GDP* functions for the four periods are shown as follows:

1965–1973:

$$\text{GDP}(E) = 579.02E + 42613 \quad (2.5)$$

Formula (2.5) is a positive *E-GDP* function; the slope of function is 579.02, which indicates that the increase of one unit electricity consumption in the three industries can show an increase of GDP 579.02 Yen. The positive intercept of the

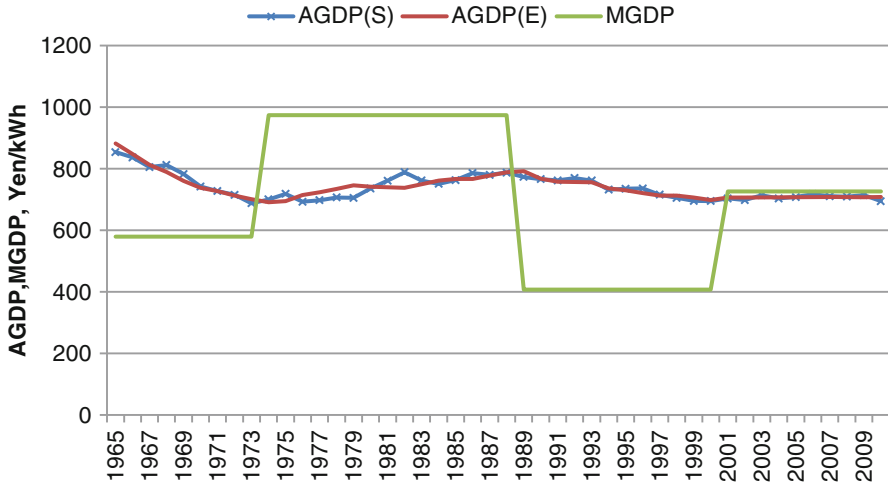


Fig. 2.45 Average GDP of electricity and marginal GDP of electricity in Japan

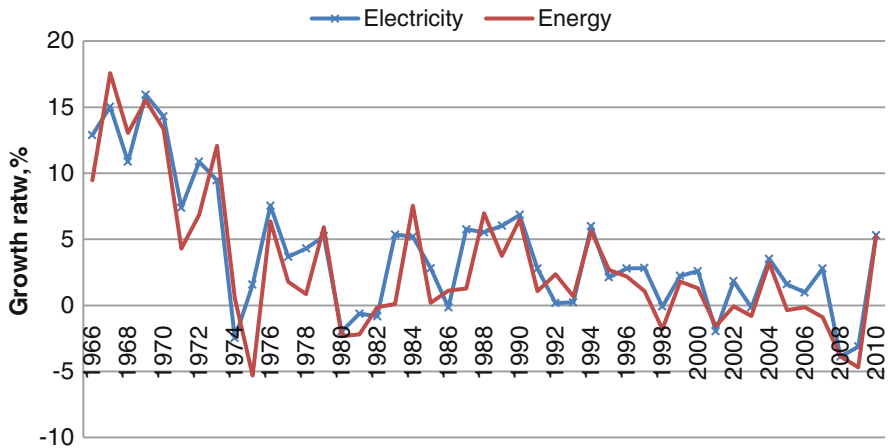


Fig. 2.46 Growth rates of primary energy and electricity in Japan (Data source: Handbook of Energy & Economic Statistics in Japan 2012)

function shows that the average GDP of one unit electricity use is in decrease with the growth of electricity consumption. As illustrated in Fig. 2.46,  $AGDP$  was higher than  $MGDP$  and it keeps declining in that period.

A negative mutation happened in 1974; thus, the  $E-GDP$  function becomes a negative function as shown in formula (2.6). The slope has increased to 973.62, i.e., the marginal GDP of electricity has a big increase from 579.02Yen/kWh to 937.62Yen/kWh. It shows the negative mutation makes the marginal representative factor productivity grow fast in Japan. And also  $AGDP$  is lower than  $MGDP$  and  $AGDP$  is increasing in this period (Fig. 2.45). The negative  $E-GDP$  function is shown as follows in this period:

1974–1988:

$$GDP(E) = 973.62E - 96337 \quad (2.6)$$

There was another mutation, a positive mutation, which happened in 1989 in Japan. The marginal GDP of electricity decreased to 407.33Yen/kWh in the 1989–2000 period (formula 2.7). Since the mutation has shown a so big change on *MGDP*, it is poor for the economy. Unfortunately, the period lasted for 12 years until another mutation happened. Figure 2.45 shows that the *AGDP* was higher than *MGDP*, and it had decreased during 1989–2000. The positive *E-GDP* functions are shown as follows in this period:

1989–2000:

$$GDP(E) = 407.33E + 211829 \quad (2.7)$$

There was a negative mutation in 2001, and it has no more data to learn if there was another mutation that happened after 2010. Thus, the period was from 2001 to 2010 in our discussion. The negative *E-GDP* function during 2001–2010 was as follows:

2001–2010:

$$GDP(E) = 726.72E - 14501 \quad (2.8)$$

The marginal GDP of electricity had increased to 726.72Yen/kWh; however, it was still lower than 973.62Yen/kWh in the 1974–1988 period. The average GDP of electricity takes up trend since the intercept of formula (2.8) is negative (Fig. 2.45). However, the *AGDP* is very close to *MGDP*, and there is not enough space for *AGDP* to grow. Maybe a mutation will happen in the near future after 2010. Although the negative mutation in 2001 meant the growth of *MGDP*, it is too low to promote the *AGDP* increase. Thus, the negative mutation is too weak to drive the economic growth.

As for primary energy consumption and industrial electricity use, their growth rates are illustrated in Fig. 2.46. The difference between energy growth rate and electricity growth rate is very small, which demonstrated that the energy efficiency in electricity use has played an important role in Japan.

The feature of each period shown in Fig. 2.48 can be discussed as follows:

1965–1973: a positive mutation happened in 1965, the *MGDP* was relatively lower (579.02Yen/kWh), annual average growth rates of primary energy and electricity consumption were relatively higher (11.45 and 5.21 %), and energy growth was higher than electricity growth.

1974–1988: a negative mutation happened in 1974, the *MGDP* was relatively higher (973.62Yen/kWh), and annual average growth rates of primary energy and electricity consumption were 1.51 % and 2.61 %, respectively, in relatively lower, while the energy growth was lower than that of electricity..

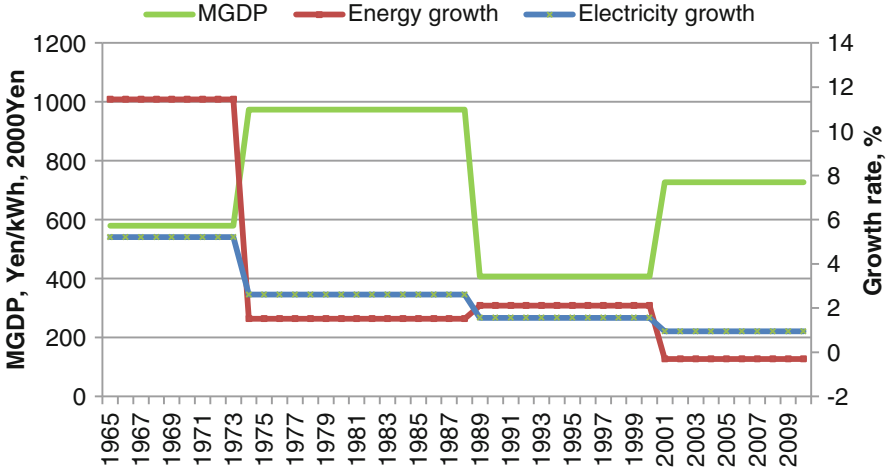


Fig. 2.47 MGDP, electricity growth rate, and energy growth rate with mutations in Japan (Data source: Handbook of Energy & Economic Statistics in Japan 2012)

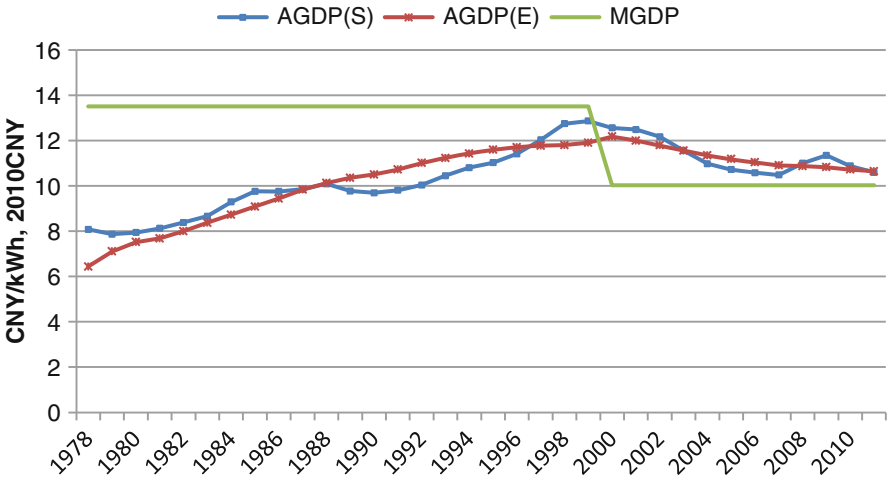


Fig. 2.48 AGDP and MGDP in China

1989–2000: a positive mutation happened in 1989, the *MGDP* was lower (407.33Yen/kWh), and annual average growth rates of primary energy consumption and electricity use were higher (2.11 and 1.56 %), and energy growth was higher than electricity growth.

2001–2010: a negative mutation happened in 2001, the *MGDP* was higher (726.72Yen/kWh), and annual average growth rates of primary energy consumption and electricity use were higher (−0.31 and 0.94 %), and energy growth was lower than electricity growth.

It is also verified that when a negative mutation happened, the *MGDP* is relatively higher, and the growth rates of energy and electricity consumption will be relatively lower; and when a positive mutation happened, *MGDP* is lower, and energy and electricity growths will be relatively higher. Thus, mutation could indirectly affect the energy and electricity demand. In other words, a positive mutation indicates the energy demand would be lower, and negative mutation means that the energy demand would be higher. It is also interesting that the energy growth was lower than electricity growth when a negative mutation happened in Japan, and vice versa when a positive mutation happened. (Why? If some readers can provide the answer, it will be valuable.)

In summary, the positive mutation period was only 9 years from 1965 to 1973; it looked good with shorter period of the low marginal representative factor productivity; the negative mutation in 1974 indicated that *MGDP* increased largely; it meant the increase of the marginal representative factor productivity with lower energy consumption; and it also looked good for the longer negative mutation period of 16 years. The positive mutation in 1989 had shown a big decrease of *MGDP* with higher energy growth, showing a sick economy. The period took 12 years. Fortunately, another negative mutation happened in 2001; the marginal representative factor productivity increased a little.

Why do the mutations happen in the national economy? What factors will affect or result in economic mutation? One factor is technology improvement. It is clear that advanced technology will improve energy efficiency, i.e., use less electricity and produce more products. Another factor is technology innovation. The new technology to produce new product will increase more electricity use in the economy, such as electric train and electric vehicle, both of them use electricity to replace gasoline. This is the growing process of electrification, which is to replace primary energy such as oil, natural gas, coal, etc. by using more electricity. Management is perhaps also a booster in energy efficiency, electrification, and production. Market demand will drive producers and consumers to balance supply and demand, for which managers have to do decision making. Market demand will reflect the economic stage, i.e., the economic mixture. In the middle stage of industrialization, the heavy industry grows fast, while in the late and post-industrialization stage, tertiary industry grows fast. Therefore, the economic mix is another factor of economic mutation.

In the case of Japan’s economic mutations, in 1974, the factor of technology improvement played a crucial role in energy efficiency, which made the *MGDP* very high during 1974–1988. In that period, Japan’s economy was in the late and post-industrialization stage, and economic structure transferred from heavy industry to tertiary industry. However, for the mutation in 1989, the factor of management played a role in lowering marginal representative factor productivity in the 1989–2000 period. The mutation rendered Japan’s economy low marginal representative factor productivity, and the *MGDP* was the lowest one. For the mutation in 2001, although the negative mutation showed the *MGDP* was up to 726.72 Yen/kWh, it was still lower than 973.62 Yen/kWh, and the *AGDP* grew very slowly. It still demonstrated that the national economy was not strong. The study of mutations can be conducted more deeply in the three industries, many sectors,

and firms or companies if more data are available. However, it can be concluded that the next mutation will be a positive one and the *MGDP* will be lower than 726.72 Yen/kWh. Since there was more space for the growth of *AGDP* in 2010, the positive mutation may happen in the next few years in Japan's economy. Then, the following mutation will be a negative one, and the *MGDP* will increase to a high level, which will bring about a bright future for the economy in Japan.

### 2.3.3 Mutations of the Economy in China

Reviewing the *E-GDP* function of China from 1978 to 2011, there was a mutation that happened in 2000 that divided China's economy into two periods with *E-GDP* functions as follows:

1. 1978–1999:

$$GDP(E) = 13.52E - 1709.3 \quad (2.9)$$

It is a negative *E-GDP* function. The *MGDP*, slope of the *E-GDP* function, is 13.52 CNY/kWh, and the intercept is negative, which means the *AGDP* will rise with the increase of *E*. As shown in Fig. 2.47, the *AGDP* changed from 6.43 CNY/kWh in 1978 to 11.9 CNY/kWh in 1999. Then, a positive mutation happened in 2000.

2. 2000–2011:

$$GDP(E) = 10.037E + 2526.5 \quad (2.10)$$

It is a positive function. The mutation shows *MGDP* decreases from 13.52 CNY/kWh to 10.037 CNY/kWh, and the intercept of the *E-GDP* function changes from  $-1709.3$  to  $2526.5$ . As illustrated in Fig. 2.47, *MGDP* is constant, while *AGDP* decreases from 12.55 to 10.59 CNY/kWh. *AGDP* is very close to 10.038 CNY/kWh of *MGDP*, which means a negative mutation will happen in a few years after 2011.

The period featured can be summarized as follows:

1978–1999: a negative mutation happened, the *MGDP* was relatively higher (13.52CNY/kWh), and annual average growth rates of primary energy consumption and electricity use were relatively lower (4.38 and 7.31 %).

2000–2011: a positive mutation happened in 1999, the *MGDP* was lower (10.037/kWh), and annual average growth rates of primary energy consumption and electricity consumption were higher (8.75 and 12.42 %).

We can see that when a negative mutation happens, the *MGDP* gets higher, the growth rates of energy and electricity consumption turn lower; on the contrary, when a positive mutation happens, the *MGDP* is lower, and energy and electricity

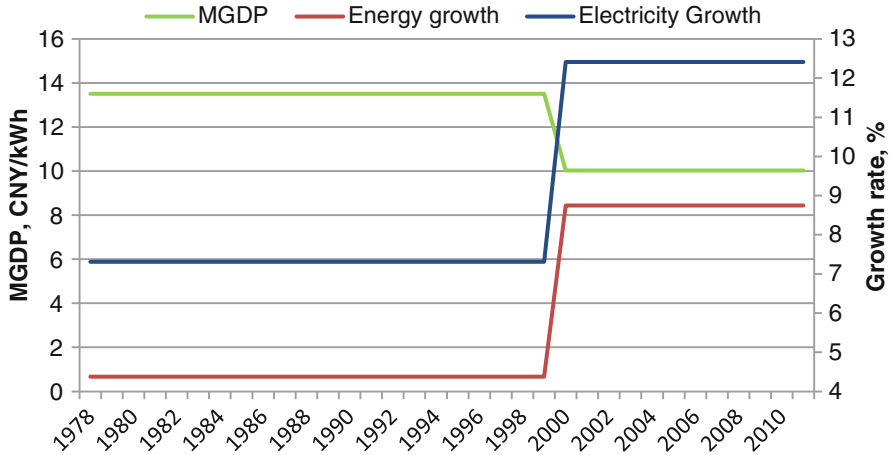


Fig. 2.49 MGDP, energy growth rate, and electricity growth rate in China

growth rates will be higher. It also shows that mutation could indirectly affect the energy and electricity demand, i.e., negative mutation means relatively low energy demand and positive mutation indicate high energy demand. It is also showed in Fig. 2.49 that the energy growth rate is always lower than electricity growth, which means the increase of electrification level is the trend of energy consumption.

In summary, the positive mutation in 1999 appeared with a decrease of *MGDP* with higher energy growth, which implies a challenge in the economy.

The next economic mutation will be a negative one with the *MGDP* increasing. It means an opportunity of growing productivity with lower energy growth in China. Then, the pollutions would be better as people expected. However, if the mutation were not powerful enough to increase the *MGDP* greatly, the economy would be in stagflation. As for the case in Japan, there was a negative mutation in 2001; the *MGDP* only increased 1.784 times. This is a warning. What is the power of the mutation to increase *MGDP* greatly? It must be the technology improvement and innovation in a suitable economic mechanism. For example, the negative mutation happened in 1992 in the US economy; the *MGDP* increased more than 4.67 times.

## 2.4 Findings

Based on the above discussions, the following findings can be summarized as:

1. Positive mutation and negative mutation in an economy will happen in turn alternatively.
2. Positive mutation will show a smaller marginal representative factor productivity and higher energy demand, while negative mutation will show a bigger marginal representative factor productivity and lower energy demand relatively. It is the cycle mutation feature.



3. If the next economic mutation in China will be a negative mutation, then marginal representative factor productivity would have a growth, the energy demand would be lower, and the situation of pollutions in China would be better. However, according to the experience in Japan since 2001, if the negative mutation were not powerful enough to increase marginal representative factor productivity greatly, the economy would be in stagflation in that period.
4. A health economy has two features: one is that the negative mutation can be powerful enough to increase marginal representative factor productivity greatly and last for a longer period without another mutation happening, and another feature is that the positive mutation shows that marginal representative factor productivity decreases only a little and another mutation will happen as soon as possible.

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